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have presented at the Congress our report and the first international tectonic map of Europe, the fruits of intensive work of over three years, done by geologists of various countries.[3]

Authors and the Editorial Board of the Map. The general work of preparing material on individual countries was done by the following geologists: Austria — H. Küpper; England — F. W. Danning, F. M. Trotter; Algeria — L. Glangeaut, A. Ker, M. Mattauer; Belgium — P. Micheau, P. Fourmarier; Bulgaria — E. Bonchev; Hungary — E. Vadas, F. Sentesh, J. Tomor, E. Schmidt, J. Fulěp; East Germany — A. Watznauer, H. Halvitz, H. Kelbel, K. Ptisch; Greenland — A. Bertelson; Greece — G. Bornovas, G. Mistardis, G. Papastamasiu, A. Paraskevaides, G. Brunn; Denmark — H. Ödum; United Arab Republic — R. A. Higazi, A. Shata; Israel — J. Bentor, A. Wroman; Iceland — S. Torarinsson; Spain — A. Almela, E. Depuy de Lome, H. Lopez Llado, H. Rios, H. Fontbot; Italy — M. Manfredini, A. Serge, R. Signorini; Cypress — F. Inghem; Morocco — M. Diurie, M. Durant-Delga, J. Marcet, M. Mattauer, P. Fallot, A. Fore-Muret, J. Schubert, G. Sutere; Netherlands — A. Tyandes; Norway — O. Holtendal, G. Bjerlikke, S. Skieretlo; Poland — G. Znosko, S. Sokolowski; Portugal — A. de Castello Branco; Romania — Ch. Georgescu, J. Dumitrescu, V. Lazarescu, O. Mirueze, G. G. Mourdjeanu, S. Paulyyuk, M. Sendulescu; Sahara — N. N. Menshikov; U. S. S. R. — M. G. Agabekov, A. A. Bogdanov, V. I. Bondarev, Z. I. Borozdina, Ye. P. Bruns, A. A. Gabrielyan, P. D. Gamkrelidze, R. G. Garetskiy, R. A. Gafarov, A. N. Geysler, Yu. N. Godin, G. M. Davydov, G. D. Dickenstein, A. Ye. Dubinskiy, S. P. Yegorov, I. I., Yengurazov, V. S. Zhuravlev, L. P. Zadov, N. S. Igolkina, S. P. Kozlenko, V. P. Kolchanov, K. O. Kratz, Yu. I. Lazarev, L. N. Maraiti, Ye. Ye. Milanovskiy, M. V. Muratov, A. I. Mushenko, V. D. Nalivkin, A. S. Novikova, A. S. Perfil'yev, L. N. Potrubovich, V. M. P'yankov, L. I. Rovnin, L. N. Rozanov, N. P. Semenenko, V. N. Sobolevskaya, V. K. Solov'yev, P. A. Sofronitskiy, A. G. Tatarinov, G. M. Teterev, D. A. Tugolesov, E. E. Fotiadi, V. Ye. Khain, L. Ya. Kharitonov, N. P. Kheraskov, M. V. Chirvinskaya, N. S. Shatskiy, E. Sh. Shikhalibeyli, A. L. Yanshin; Turkey — N. Egeran, I. Kettin, E. Lan, K. Erentoz; West Germany — H. Von Hertner; Finland — A. Simonen; France — J. Gogel, M. Grendor, R. Damer, M. Casteras, M. J. Lienhardt, M. Orgeval, P. Pruvost; Czechoslovakia — T. Buday, W. Zoubek, O. Kodym. A. Matejka, M. Magel, M. Maŝka, J. Svoboda; Sweden — N. Magnusson, B. Asklund, O. Kulling; Yugoslavia — Kosta B. Petkovich.

In addition to these, individual geologists were invited by the Subcommission to participate to process and refine the authors' layouts or to prepare from publications the layouts for those areas for which material had not been received from the national organizations. Thus, A. A. Bogdanov prepared the layout for Ireland and partipated in the preparation of Icelandic and French layouts; A. V. Dolitskiy took part in preparing the layout for the Syrian area of the U. A. R. and of Lebanon; L. Dubertres — of Turkey, Syria, Lebanon, and Iran; K. A. Klitin made a map of Spitzbergen; V. P. Kolchanov participated in the French layout; N. N. Menshikov compiled a map of Syria; M. V. Muratov, a layout of the Swiss Alps; he also participated in the work on the Alpine zone (Yugoslavia, Albania, Bulgaria, Turkey); J. Castanie compiled a map of Tunisia; N. A. Pavlovskiy participated in the French layout; N. A. Syagayev, in the work on the Egyptian part of the U. A. R.; P. Fallot presented material on the Alpine zone of Spain and on the western Mediterranean; V. Ye. Khain prepared the north Iranian layout.

The Editorial Board consisted of representatives from geologic organizations of all countries participating: A. Almeda (Spain), M. J. Betier (France), J. Bentor (Israel), A. Bentz (West Germany), E. Bonchev (Bulgaria), G. Bornovas (Greece), E. Vadas (Hungary), A. Watznauer (East Germany), H. Von Hertner (West Germany), L. Glangeaut (France), J. Gogel (France), M. Diourie (Morocco), L. Dubertrés (France), W. Zoubek (Czechoslovakia), F. Ingham (Cypress), A. de Castello Branco (Portugal), J. Castanie (Tunisia), K. O. Kratz (U. S. S. R.), H. Küpper (Austria), N. Magnusson (Sweden), M. Manfredini (Italy), J. Marset (France), A. Matejka (Czechoslovakia), N. N. Menshikov (France), P. Micheaut (Belgium), M. V. Muratov (U. S. S. R.), G. Mourdjeanu (Romania), V. D. Nalivkin (U. S. S. R.), G. Papastamasiu (Greece), Kosta V. Petkovich (Yugoslavia), P. Pruvost (France), W. Pew (Great Britain), A. Simonen (Finland), S. Sokolowski (Poland), A. Tiandena (Netherland), F. M. Trotter (Great Britain), P. Fallot (France), A. Fore-Muret (Morocco), R. A. Higazi (U. A. R.), O Holtedahl (Norway), S. V. Chernook (U. S. S. R.), J. Schubert (Morocco), K. Erentoz (Turkey), A. L. Yanshin (U. S. S. R.).

N. S. Shatskiy was Chairman of the Editoral Board; A. A. Bogdanov, Academic Secretary; H. Stille, Honorary Chairman.

Among the many participants in the general work, contributing to the timely completion of the map we particularly commend H. Von Hertner, L. Dubertres, W. Zoubek, K. O. Kratz, N. Magnusson, J. Marcet, N. Menshikov, M. V. Muratov, V. D. Nalivkin, and J. Schubert, who not only presented all material necessary for the map but took an active part in making up the legend and editing the map and contributed

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[3]The report was read in abbreviated form by A. A. Bogdanov, on behalf of the late N. S. Shatskiy, at Copenhagen, August 18, 1960, before a session of the Subcommission on the Tectonic Map of the World. Its text was written in May and June, 1960.

h of their time and effort to its timely com-ion.[4]

Ve also deem it necessary to mention the at assistance to the organization on this work ll its stages, by F. Blondel, President of the nmission on the Geologic Map of the World.

The vast work of map making, the delineation ayouts, and the preparation of its sheets for nting, was done by a large group of collabo-ors from the Commission on Tectonic Maps he Geologic and Geographic Section of the . S. R. Academy of Sciences, Geological In-ute of the U. S. S. R. Academy of Sciences, Moscow State University, under the direc- of S. V. Chernook. Among the members of group were I. P. Golubchikov, A. G. Gosteva, '. Dolitskiy, N. M. Zaytseva, S. A. Igonina, . Kolchanov, S. S. Levitina, V. V. Meyyer, . Nizkokhataya, M. G. Pavlenko, I. I. Popova, .. Semova, T. S. Sonina, and V. I. Shuvalov. general direction of all work was exercised he authors of this article.

Material of the map. Most of the layouts for onic maps of individual countries, used as basis for the tectonic map of Europe, were npiled from most recent geologic and geo-sical studies, as well as from drilling data. ny of these data have never been published ore; as such, they are of particular interest. ong these new maps are those of England, rocco, Sahara, the Baltic shield, certain ts of the Russian platform, Poland, Hungary, A considerable number of maps had been wn by their authors on a scale larger than of the general map (from 1:500, 000 to 000, 000) and some had to be slightly simpli- . In detailing some individual areas, small n rule (Ireland, Switzerland, the Armorican central massifs of France, and northern n), we had to go only by already published os of various scales (from 1:200, 000 to 500, 000) and by published descriptions.

n the last two years, some of the layouts of se tectonic maps or of those drawn from n, have been published. Among them are following:

1. Mapa tektoniczna Polski. Warsaw, 1959.

2. St. Sokolowski, Jerzy Znosko, Elements ncipaux de la téctoniques de Pologne. Inst. olog. Odbitka z prac., t. 300, szecs II, rsaw, 1960.

3. General tectonic map of Czechoslovakia, 000, 000. Prague, 1960.

4. Tectonic development of Czechoslovakia. Compiled by T. Nunday, O. Kodya sen. M. Mahel, M. Maŝka, A. Matejka, J. Svoboda, and V. Zoubek. Prague, 1960.

5. H. Küpper, Erläuterungen zu einer tektonischer Übersichtsskizze des weitern Wiener Ruames. Mitt. Geol. Ges. in Wien. Bd. 53, Vienna, 1960.

The geographic base of the 1:2, 500, 000 tectonic map of Europe was compiled and published by the Main Administration of Geodesy and Cartography at the Ministry of Geology and Mineral Conservation of the U. S. S. R., as commissioned by the Section of Geologic and Geographic Sciences, the U. S. S. R. Academy of Sciences. It has been drawn in sufficient detail to satisfy the needs of a tectonic map, including the continental areas, interior European seas, and a part of the northeastern Atlantic.

The geographic base of the map is drawn in Lambert's projection with two standard parallels, $\varphi_1 = 41^\circ$ and $\varphi_2 = 65^\circ$. In this projection, most of the map area is very little distorted.

The elements of the geographic base are as follows: a one degree grid system, shore line, a sufficiently detailed hydrographic network, city markers (differentiated by population, with state capitals indicated), terrestrial and submarine volcanoes, and sea bottom relief which is represented by isobaths 0, -100, -200, -500, -1000 m, and every 1000 m at greater depths.

It was decided at a session of the Commission on the Tectonic Map of the World (Paris, April 1958) to dispense with a representation of topographic contours on the geographic base of the tectonic map of Europe, as well as the various artificial structures and state boundaries, in order not to burden it with too many lines and to avoid confusion.

The map is laid out in 16 large sheets (Figure 1). Part of sheets One and Five, in the upper left corner, show the title and all necessary information on the authors, Editorial Board, etc. The lower right sheet (16) is reserved for the legend.[5] There are two insets in the upper part of the map: Spitzbergen in Sheet Three; and most of the northern part of Novaya Zemlya, in Sheet Four.

Thus the map comprises all of Europe; its eastern sheets show the western margins of Siberia, Kazakhstan, and the Transcaspian region. The southern tier of sheets shows the northern margin of Africa and all of the Mediterranean basin.

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[4]The Tectonic Map of Europe is being prepared publication by the Main Administration of Geodesy Cartography, Ministry of Geology and Mineral servation of the U.S.S.R.

[5]A tectonic map is contemplated for the area of Sheet 16. At the suggestion of L. Dubertret, the work on it is underway. Its geographic base is ready.

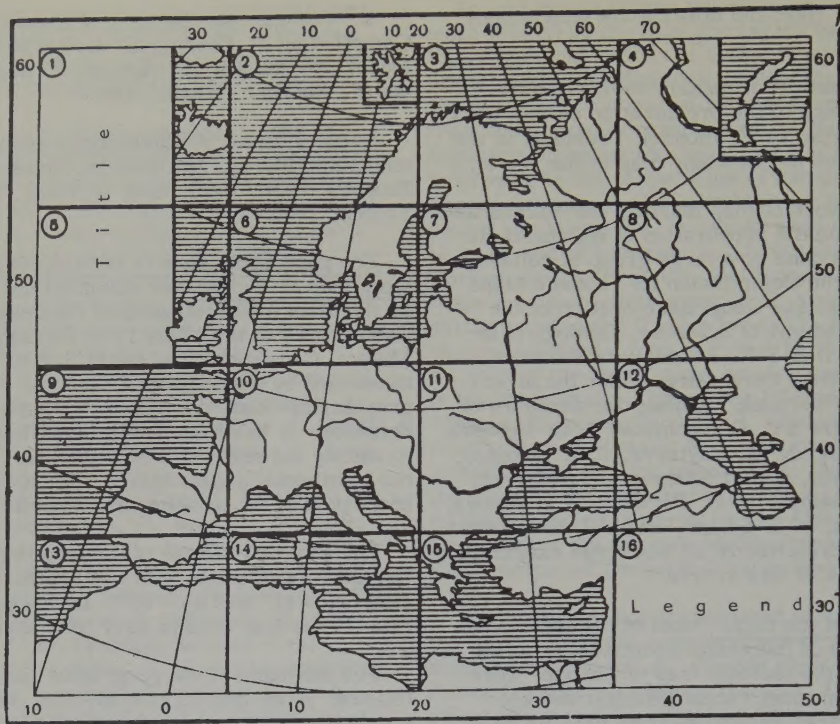

FIGURE 1. Diagram of the sheet arrangement in the tectonic map of Europe.

Advanced prints of the geographic base were dispatched to all organizations participating, for their criticism, corrections, and refinement. The final prints incorporated all recommendations. Both the base and the finished map were prepared for printing in two languages, French and Russian, with all geographic and city names in their original spelling.

2. TYPES OF TECTONIC MAPS AND THE PURPOSE OF THE MAP OF EUROPE

Tectonic maps are becoming ever more important in modern geology. Their compilation is one of the principal effective methods of tectonic analysis, especially in solving practical problems. A tectonic map is also the most condensed graphic representation of tectonic synthesis. This is the reason why no regional geological work, aspiring to any degree of completeness and substantiation of conclusions, can do so without tectonic maps.

Tectonic maps and schemes are almost as old as geologic maps. One of the earliest attempts was the Tectonic Scheme of the Jurassic Mountains, by A. Gresslie, published back in 1938. However, such schemes were for a long time subordinate to geologic maps; they were of an illustrative nature, interpreting by means of symbols the geologic map and the structure of the area, often difficult to convey without tectonic explanations. Such schemes are still quite common.

The slection of such schemes and their symbols has not been subject to definitely establish rules, although the following graphic method ar common: 1) contour lines on certain geologic surfaces, such as unconformities, etc. ; 2) symbols for various tectonic forms (folds, normal and reverse faults, nappes, etc.). The two types are often directly superimposed on a geologic map.

About the turn of the century, tectonic schemes were extensively used as illustrations to major geologic and tectnoic generalizations (E. Suess, A. Heim, F. Kossmat, L. Cobert, R. Schtaub, etc.). The publication of structural maps in geologic atlases of the U. S. G. S. belongs to that period. However, independent work of compiling tectonic maps did not begin until the second decade of this century. By that time, and as a result of the extensive explorati for petroleum, coal, and ore deposits, and arte sian basins, the immense practical value of structural geology and of tectonic maps had become clear. It should be noted that these tectonic studies have become possible only in our time, when geologic sciences has ceased to be mere history of the earth's surface and organic life and has become instead a new science of th structure and evolution of the crust.

the nature of their legends, modern tec- maps can be divided arbitrarily into: 1) tural and 2) tectonic (strictly speaking), the second group subdivided into a) regional) general.

rdinarily, structural maps are those where ymbols represent, mostly or exclusively, norphology of tectonic structures, with age ols indicating the tectonic development of ea either absent or subordinate. An ex- e is the familiar 1:2, 500, 000 map of the (1944).

contrast to structural maps, the tectonic emphasize both the structural and age cts of the legend. Thus, they combine the hology and the history of development. genetic basis of these maps is always con- ious: it is paramount, sometimes to such an t (in the so-called "tectonic differentiation") as to relegate the morphologic symbols cond place.

ne difference is perhaps just as great be- n general and regional tectonic maps. The nd for the regional tectonic maps is always to fit a particular area; for this reason, egend on one map is seldom suitable on the e for a tectonic representation of any other nents of the crust, however genetically lar. On the other hand, the principle of the nd for a general tectonic map is to represent tructural and tectonic features of the crust; the principle of a legend for, say, the ne zone of Europe, can be used in a tectonic of the Himalayas or of the Near East Alpine . In addition, the symbols must be general- milar to the symbols for other folded zones e same age.

he problem of the regional tectonic map nd and its differences with that for general s is quite complex. For a regional tectonic there is the classic map of the hercinids, . Kossmat, as well as the familiar tectonic of the Western Alps, by Albert Heim. For ral tectonic maps, there are those of the S. R. (1:4, 000, 000 and 1:5, 000, 000, 1956), of Africa (1:10, 000, 000, 1956).

is well known that the zonal differentiation e Middle European hercinids (marginal gh, Reno-Hercinian, Saxo-Thuringian, lanubian zones, southern externids) is re- al. As such, it cannot be used with cer- y throughout the latitudinal zone of that h, east of the Czech massif and west of the ges and Schwarzwald, let alone for all of the opean hercinids. The same appears to be with regard to the regional tectonic legend he Alps; i. e., the province whose structure been studied for a long time, and where geo- c mapping has attained a high level of ac- cy.

ectonic zones of the Swiss Alps, firmly established in geology (the Molasse marginal trough, zones of Helvetian and Pennine nappes, East Alpine dinarids, etc.), are traceable, in- completely and with difficulty, as far as Vienna; their identification in the Caucasus and Asia Minor is utterly impossible.

However, these regional tectonic subdivisions of the Mid-European hercinids and alpids have many common features, a fact explained in modern geology be general regularities in the structure and development of geosynclinal folded systems. These common features are so char- acteristic that they forced E. Wegmann, as early as 1928, to look for homologues of Alpine tectonics in Precambrian folded systems of the svekofennidss and karelids, while S. Bubnoff de- tected a great similarity in the structure of the karelids with the Variscian zonation of Middle Europe.

Thus, the basis accepted for symbols in a general tectonic map does not lie in specific structures and structural zones of regional maps but rather in general zones recurring in the structure of folded systems and platforms for all orogenic epochs, for each epoch, and for all geo- synclinal provinces of the world. It is only from this general comparative, tectonic point of view that geotectonics has succeeded in establishing the principal types of structural forms, their regular distribution in folded and platform pro- vinces, the order of succession responsible for their zonal structure, and the lateral change and disappearance of folded belts. Thus, it became possible to discern the laws of morphogenesis, of tectonic evolution, and of their vagaries in the course of the Neogene megachron, and per- haps to solve the most complex problems of tec- tonic features at initial stages of crustal develop- ment during the preceding ancient megachrons.

We believe that, thanks to these general principles of a legend, the compilation of such tectonic maps is one of the methods of tectonic analysis, wherein new problems and their solu- tions are not isolated but are put in apposition to the general tectonic background of vast conti- nental areas and of the earth as a whole.

The tectonic map of Europe, compiled by the collective work of international gelogists, is a general tectonic map. We believe that its signi- ficance far exceeds that of a conventional re- duction of regional tectonic maps and schemes. As such, it undoubtedly will be of assistance in solving major theoretical problems.

3. THE MAP LEGEND AND THE BASIC PRINCIPLES OF ITE COMPILATION

The legend was a major topic of discussion, both in the beginning and in the course of the work on this map. Originally, symbols used in the 1956 1:5, 000, 000 tectonic map of the

U. S. S. R. were tentatively accepted. However, substantial changes and additions were introduced as the work progressed, some of them dictated by the latest achievement in tectonics, others influenced by the experience with index tectonic maps of France (1951), the U. S. (1944), Canada (1954), Africa (1956), U. S. S. R. (1952 and 1956), and a number of regional maps of the Alpine and Hercinian provinces of Europe.

The age of folding was the basic criterion for differentiating the map area into natural geologic regions. This age was determined as that of the intensive deformations in folded geosynclinal provinces or, more precisely, as the time when a folded (geosynclinal) province became a platform. These two categories of geologic structures, folded zones and platforms, are characterized by their peculiar associations of sedimentary and volcanic rocks, their specific series of intrusives, their own manifestations of tectonic movements, metallogeny, etc. Periods when folded systems become platforms are natural time markers in the evolution of the earth, the dates of sharp qualitative changes in large crustal segments. For this reason, the principle of isolation of noncontemporaneous provinces is natural and quite objective.

In accordance with that cardinal principle of legend compilation, folded provinces of different ages were differentiated in Europe and adjacent parts of the neighboring continents, viz: Archean, Proterozoic (Svekofannian, Karelian, Gothian, etc.), Baykalian (Assyntian, Cadomian, Hercinian (Variscian), and Alpine.

At the present time, there is no longer any doubt that the evolution of the earth occurred in very long cycles, each embracing several eras. These immense time intervals may be called megachrons. Only the last of them is discernible to any extent. The older megachrons are more obscure, although there is evidence of at least two of them. The latest megachron comprises the Riphean, early Paleozoic, late Paleozoic, Mesozoic, and Cenozoic eras, terminating respectively in the Baykalian, Caledonian, Hercinian (Variscian), Mesozoic, and Alpine epochs of folding.

During the latest megachron, named Neogene by Stille, a major reconstruction of the crust and the formation of its principal present structures, among them the ancient platforms with their extremely thick nonmetamorphosed sedimentary mantles, has occurred. All geosynclines and folded provinces, beginning with the Baykalian (Assyntian) were apparently formed at that time. Associated with rocks of this megachron are most ore deposits, all coal and petroleum basins, etc. Its significance in theoretical and applied geology is so great that it should be specially designated in the legend of tectonic maps. This is achieved by a color scheme for all its exposed folded formations, different from that adopted for older megachrons.

An analysis of the history and evolution of individual folded structures shows that the closure of geosynclines, the termination of the formation of marginal troughs, and the change from geosynclinal to platform stages, are not always associated with the same stratigraphic level. It is well known that the Hercinian Urals (Permian to Lower Triassic) are younger than the Hercinids of Middle Europe and England (Upper Carboniferous), as witness the fact that both Lower Permian and Lower Triassic beds fill the Uralian foredeep (the south marginal trough of Bashkiria). Similarly, only Carboniferous beds were deposited in the foredeep of the West German Hercinids, while Permian beds both here and in England, make up the base of an epi hercinian platform mantle.

The Taconian is well known along with the Caledonian folding; it is of the same Caledonian period of tectogenesis. Finally, according to N. S. Shatskiy, the Baykalian folding, too, shows evidence of two similar epochs. In some massifs, this folding is associated with the Cambrian-Algonkian boundary, while some others are the result of younger folding, of the same Baykalian period (Middle Cambrian). The expediency of assigning the latest movements to the Baykalian (Assynthian, Cadomian) rather than to the Caledonian folding is also suggested by F. Lotze, for the Assyntian-Paleozoic massif; the same conclusions has been recently arrived at by M. Maŝka and V. Zoubek, for the Czech massif.

Early in 1959, V. Zoubek proposed, in addition to the use of colors, the following letter symbols for folded provinces of different ages: B for the Baykalian (Assyntian, Cadomian); C for Caledonian; V for Variscian (Hercinian); and A for Alpine.

These symbols were accepted by the Editorial Board. In addition, symbol PZ was adopted for provinces of undifferentiated Paleozoic folding, locally including the Precambrian. The following symbols were designated for Precambrian orogenic complexes: Ar for Archean folding; SF for Svekofennian; K for Karelian and its equivalents; G for Gothian; I for Jotnian complex; and PC for undifferentiated Precambrian foldings.

Later on (1960), A. Watznauer proposed somewhat different symbols for the age of consolidated orogenic zones: a for Assyntian; c for Caledonian; v for Variscian; m for Mesozoic; and n for Neozoic. He also proposed letter symbols for complexes embraced by an entire megachron. We believe that to be superfluous because the megachrons are well identified by the entire complex of orogenic eras. As to the symbols for epochs of folding, we do not

much difference between our capital and A. :znauer's small case letters. However, we e issue with the use of the letter a for the syntian epoch and n for the Alpine; it is hardly rect to change the name, "Alpine epoch", to ozoic". We also believe that the Assyntian ch is a synonym for Baykalian; therefore, er B is quite appropriate, especially so if the name is kept for the Alpine epoch.

One of the knottiest problems of a legend is sented by symbols for ancient massifs lo-ed in younger folded belts, such as the cen-l massif of France, Czech massif, and warzwald. These can be regarded either as ken-off blocks of an ancient pre-Riphean form, reworked by later tectonic processes metamorphism, or else as provinces of an lier consolidation of a given folded system, h as a Caledonian consolidation amidst a iscian folding.

Such massifs are marked in the map by ble letter symbols, to correspond to their er and younger folding. For instance, the ot folded basement in southern Norway, re-ked by Gothian folding, is marked by symbol ; the Karelian and older massifs, reworked Variscian folding (such as the Sudeten), carry symbol KV; Baykalian (Cadomian) folded plexes of the Armorican and other massifs, orked by Variscian folding, carry latters

Median massifs within the Alpine folded pro-e (Rhodope, etc.) are outlined. Baykalian younger geosynclinal provinces are divided eu- and mio-geosynclinal zones.

As mentioned before, tectonic zonation is of the most important criteria of folded geo-clinal zones. In a regional tectonic sub-sion, such zones are readily identified by r names (Panninicum, Moldanubicum, etc.), n their characteristic structural and petro-phic features. A subdivision of tectonic es is the most valuable feature of regional onic maps. It must be preserved in general onic maps, as well. The most common fea-e of tectonic zonation of many folded pro-ces is the great difference between the outer inner folded zones. The outer zones are inarily amagmatic, while the inner ones are e commonly saturated with volcanic forma-s and intrusive massifs.

Viewed in this way, the outer zones corre-nd to miogeosynclines of H. Stille and M. ; the inner zones are their eugeosynclines. accept the Stille terminology as a synonym, ause miogeosynclines, as a system, prob-y exist almost independently of eugeosynclinal tems, although that remains to be demon-ated.

Eu- and mio-geosynclinales are distinguished not only by their igneous activity but also by differences in their sedimentary and volcanic series. Several structural stages are always present in folded geosynclinal structures. Each of these, corresponding to a definite stage of development of the folded province, is made up of rock associations usually separated by unconformities from the overlying and underlying associations.

The structural stages were differentiated by the types of such associations corresponding to early stages of geosynclinal development (for instance, the spilite-keratophyre, jasper, and siliceous shale formations), the middle (assorted graywackes, shale, and carbonate associations), and the later (flysch, molasse). The latter originate in the closing stages of geosynclinal development when the downward movements in them are replaced by upward ones and when mountain systems begin to form.

It was possible to differentiate structural stages in the Karelian, Caledonian, Variscian, and Alpine folded provinces.

Folded structures of the Alpine province are differentiated in the map into structural stages and substages. This affords a better representation of the structure and development of individual folded systems.

Special symbols are reserved for marginal troughs as a special type of structural stages in the Variscian and Alpine folded provinces. They are marked with horizontal bands of a color corresponding to the upper structural stage of a given folding.

Of great importance is the differentiation in a map of interior and intermontane troughs developed simultaneously with marginal troughs (such as the Hungarian trough, Atlas interior troughs, etc.).

The subdivision of structural stages presented one of the most difficult tasks because of the unavoidable effect of the personal factor in evaluating geologic phenomena. Withal, this subdivision is extremely important. A representation of stages raises the structural value of a map and introduces in the legend additional historical geologic elements.

We believe the differentiation of mio- and eugeosynclines, along with structural stages and marginal and interior troughs, to be a quite adequate representation of the zonation in folded systems and of the nature of that zonation. By introducing such symbols, we top, in a manner of speaking, the method of zonal differentiation used in regional tectonic maps and raise the accuracy of general maps to the regional level.

<u>Representation of main structural elements in platforms.</u> One of the typical features of

platform structures is the presence of a well expressed folded basement and a platform mantle, separated by major breaks and angular unconformities.

The platform basement, made up of metasedimentary and metavolcanic rocks of a geosynclinal series and cut by intrusions, is exposed in shields and occasionally in the crests of anteclises. In that event, it obviously is divided in the map into zones of different folding epochs, with structural zones subdivided within each zone.

In the shields, the folded basement may occur at various depths, often great, being concealed under the platform mantle. It is essential to represent its relief in such places, in adequate detail, in absolute elevations, by means of contours and differential coloring. Naturally, the contour interval depends on our knowledge of individual provinces. In most instances, it is 500 m, down to 2000 m; and 1000 m below that.

Platforms, like the folded provinces, are differentiated by their age. Components of the geologic structure of Europe are, first, those structures having originated when the Baykalian (assyntian, Caledonian, and Variscian (Hercinian) folded provinces became platforms; second, the vast expanses of Europe, Asia, and Africa occupied by ancient platforms with their Archean-Proterozoic basements. Ancient platforms, unlike the younger ones, originated at the beginning of the Riphean and possibly represent blocks remaining of an immense Proterozoic platform.

In a number of regions, the sedimentary mantle of the platforms (particularly epivariscian) forms folds similar to miogeosynclinal types (southern France, North Africa, etc.). These regions age designated by special symbols.

Some petrographic symbols. The symbols named above designate 1) the age of folded basements and platforms; 2) types of geosynclinal formations (mio- and eugeosynclines); and 3) structural stages. These are tectonic symbols showing the age and development of principal structures identified in an area. Certain data supplementing the tectonic description of units so identified are designated by superimposed hachures. Such data pertain to 1) types of sedimentary and volcanic associations (formations); 2) types of intrusive bodies; and 2) metamorphism.

Types of sedimentary and volcanic associations (formations). An attempt has been made to indicate on the map, where possible, the areas of development of the most common volcanic and sedimentary rock associations (formations) which characterize certain simple features of the tectonic development of individual structural units. The following formations have been indicated by such supplementary linear symbols: a) leptite and jaspilite; b) spilite-keratophyre and similar geosynclinal volcanic formations; c) terrestrial volcanic flows, of Neogene, Quaternary, and Recent age; d) similar extrusives but pre-Neogene within platforms, including traprock (with age indicated by a stratigraphic index); e) geosynclinal limestone formations; f) barrier reefs; g) flysch; h) coal measures; i) molasse.

We would point out, in this connection, that the importance of formation (association) types in clarifying the evolution of geosynclinal systems was emphasized very early by L. Cobert, who gave the names flysch and molasse to the last stages of geosynclinal development. Consequently, in our map, too, structural stages coincide with the provinces of distribution of one or another formation or a complex of formations.

Intrusive massifs are just as important as the sedimentary and volcanic associations, in a description of various tectonic conditions, and their inclusion in a map is obviously necessary. However, the scale of our map (1:2, 500, 000) precludes a representation of all important structural features, except for position, dimension, age, and composition. Accordingly, intrusive bodies are outlined within their present erosional boundaries, as is done in geologic maps, without a breakdown of the structure of their component plutonic bodies.

It was possible to subdivide the granitoid intrusions by their associations with definite stages of tectogenesis, into early orogenic, late orogenic, and anorogenic.

Special symbols are reserved for zones of metamorphic schists in Paleozoic and Alpine folded provinces. Zones of migmatization and granitization are indicated for Precambrian and Paleozoic tectonic structures.

Symbols for structural features. Several types of major structures are identified by symbols and lines. The selection of symbols was guided by earlier tectonic maps of various countries; more specifically, advantage was taken of the rich experience of American geologists in their compilation of the 1944 tectonic map of the U. S.

Stratigraphic contour lines are the perfect method of cartographic representation of structural forms. They are precise, but their use on maps at such a small scale (1:2, 500, 000) is possible only for very extended bodies with a considerable difference in elevation, no less than 200 or 300 m, under platform conditions, so that such a body can be represented by at least two or three contours. For this reason, contours were used only to represent the

ctonics of platform mantles and of certain ermontane troughs and foredeeps.

The over-all structure and major components are represented by colored contours of rious patterns. The datum horizons are ferent for different parts of the map. Two iteria were used in their selection; 1) the gree to which they reflect the structure of region; and 2) how much we know about it, rough drilling and geophysical study.

The most important contours are drawn on e folded basement: they delineate the main uctures of the platforms and relief of the ded metamorphic basement. These conurs are black, as they are in the 1956 map the U. S. S. R. They are emphasized by ading the color of the platform mantle, the ensity of shading decreasing with depth. is method affords a ready means of superposing the contours drawn on various marker rizons of the mantle over the platform color d over the basement contours, thus giving pth to a structure. The contour interval for e basement is 500 or 1000 m; for marker rizons in a platform mantle, 50 or 100 m, 0 m, and locally 500 m.

Symbols for tectonic forms and boundaries e the same as commonly used in tectonic aps.

First, there are symbols for fold, antines and anticlinoria, with their conventional bdivisions into a) upright, b) recumbent, and overturned. The direction of overturning indicated at an arrow. Then there are mbols for synclines, where necessary, and anticlines and synclines in the folded basent underneath the platform mantle.

Special symbols are reserved for arched lifts and subsidences, of the domal and canticlinal types, depressions and troughs, lt domes and anticlines: a) exposed or proven drilling and shooting, and b) determined from avimetric data.

Second, there are symbols for tectonic eaks: normal and reverse faults, strikep faults, flexures, flat flexures, flat overusts and nappes, and tectonic windows and ppe remnants (tectonic "klippen").

Undifferentiated tectonic breaks are specify designated as are those concealed under act platform deposits. Tectonic sutures, inding deep rifts, regional flexures, etc., are so identified.

Finally, the third group of symbols is for tectonic boundaries and lines: tectonic troughs, the most pronounced segments of internal troughs, and provinces of salt tectonics. This group includes the tentative boundaries of median massifs, general trends of folded provinces, and trends buried under the platform mantle.

In addition the map shows the position of all known centers of present and ancient volcanic activity: 1) terrestrial and submarine volcanoes (active now or during historic times) and 2) extinct volcanoes (Quaternary and Tertiary, as well as certain Mesozoic volcanoes).

Brief observations on a future improvement of the tectonic map legend. As pointed out before, the legend of the 1958 tectonic map of Europe was based on symbols of the 1:5, 000, 000 tectonic map of the Soviet Union, published in 1956. A comparison of the two maps shows that, although principles of the U. S. S. R. map were carried out in the map of Europe, they were substantially modified and refined. We shall list here what we believe to be desirable improvements in the principles and symbols of general tectonic maps.

Undoubtedly, a differentiation of folded zones by age of folding, and of platforms by time of origin, is objective and theoretically substantiated. As of now, a better method of subdividing the principal tectonic units of crustal structure is hardly possible. However, certain refinements over the legend for the 1956 U. S. S. R. maps were introduced in the European map legend. First, the folded provinces are combined into complexes, in accordance with the general course of evolution of the crust, and each stage of folding is regarded as that of structural development. Second, the legend for pre-Riphean (pre-Sparagmites) folding periods in the Baltic shield and Ukrainian massif was made more detailed.

The need for additional refinement of the legend of pre-Riphean folded belts is obvious, not merely for tectonic purposes but also for geochronology, particularly for absolute dating. However, a continued study of the post-Algonkian folding subdivision by age is also desirable. As shown by the experience of the U. S. S. R. Academy of Sciences Geological Institute on a tectonic map of Asia, it is wrong to go by the well defined orogenic epochs of Europe, in mapping more extensive areas of the world. There is no doubt but that such extended studies will affect the future tectonic subdivision of Europe, as well; they certainly are essential for a tectonic map of the world.

We believe that a zonal differentiation of folded belts and their subdivision along the

trend can be accomplished only through a subdivision of structural stages and geosynclinal types. It appears that such subdivision is best done not by structural features alone (unconformities) but by the types of sedimentary and volcanic rock associations, as well, and by a natural series of intrusive formations. There is still much that is subjective in the differentiation of structural stages and eu- and miogeosynclines, in both the U. S. S. R. and European tectonic maps, and much work remains to be done in that field.

The situation is especially poor with regard to classification of major and deep faults, sutures, trends, etc., in tectonic maps. This is true for representation and for the nature of these deformations.

4. CERTAIN PRINCIPAL TECTONIC ELEMENTS OF EUROPE AND THEIR REPRESENTATION IN TECTONIC MAPS

The tectonic map of Europe includes a vast complex of major tectonic provinces different in their structure and geologic history (Figure 2). It encompasses the East European Precambrian platform; Archean formations of an ancient Erian platform in northwestern Scotland in the extreme northwestern corner of the map; a rim of the Canadian shield in Greenland; and

northern margin of the Precambrian Afri- n platform, in the south. Located between se ancient platforms and east of the Russian eld, are vast belts of Paleozoic folding ided into Caledonian and Variscian.

true to its southeastern and southwestern corners and to its entire extension below the marine basins, north of the Varanger-Kanin line.

The southeastern corner of the Russian

FIGURE 2. Tectonic classification of Europe

Provinces of Archean and Proterozoic folding (Precambrian platforms): 1 - platform shelves of chean and Proterozoic folded complexes: A - Archean massifs; SF - svekofennids; K - karelids; G - hids; 2 - provinces with a shallow basement (buried slopes of shields and anteclises); 3 - pronces with a deep basement (syneclises).

Province of Baykalian folding: 4 - Baykalian outcrop areas.

Provinces of Caledonian folding: 5 - Caledonian outcrop areas.

Provinces of Variscian folding: 6 - Variscian outcrop areas; 7 - median massifs within Varisan areas and made up of Baykalian and older folded series partly reworked by Caledonian and Varisan movements; 8 - areas where the Variscian folded complex is overlain by a Mesozoic and Cenozoic atform mantle; 9 - marginal troughs.

Provinces of Alpine folding: 10 - Alpine outcrop areas (miogeosynclinal zones); 11 - same but geosynclinal zones; 12 - median massifs; 13 - marginal and interior troughs.

Structural symbols: 14 - boundaries of geosynclinal folding for various tectonic epochs; 15 - end of folded structures; 16 - outlines of internal troughs, downwarps, syneclises, anteclises; - regional faults and tectonic sutures; 18 - direction of overturning and shifting of folds.

Numerals in Map:

Ancient platforms. East European platform: 1 - Baltic shield; 2 - Ukrainian shield; 3 - ronezh anteclise; 4 - Volga-Ural anteclise; 5 - Mazovec-Belorussian anteclise; 6 - Moscow anteise; 7 - Baltic syneclise; 8 - Pachelma subsidence; 9 - Pre-Caspian syneclise; 10 - Great Donbas ough; 11 - Donets basin; 12 - Bol'shezemesk Tundra syneclise; 13 - east Spitzbergen massif; 14 - nan folded trench. Eria platform: 15 - Iceland; 16 - zone of Lewis gneisses. African platform. ields: 17 - Regibat; 18 - Tuareg; 19 - Arabian; 20 - Anti-Atlas massif; 21 - Tilremt uplift; 22 - nada uplift; 23 - Ougarta zone; 24 - Tindouf syneclise; 25 - Reggane syneclise; 26 - Lower Lahara neclise; 27 - Libyan syneclise.

Caledonids: 28 - east Greenland; 29 - west Spitzbergen; 30 - Scandinavia; 30 - Great Britain Ireland; 32 - Brabant massif; 33 - Central Kazakhstan.

Variscids: 34 - southern Ireland and southern England; 35 - Armorican massif; 36 - Morvan; 37 southern France; 38 - Ardennes-Sudeten-Silesia; 39 - Iberian Peninsula; 40 - Corsica and Sardinia. cient cores: 41 - Vendée; 42 - central massif; 43 - Vosges and Schwarzwald; 44 - Czechoslovakia. bsidences within the epi-Paleozoic platform of Europe: 45 - Polish-German; 46 - east England; 47 London basin; 48 - Paris basin; 49 - Aquitanian basin; 50 - Manche trough; 51 - Mesozoic subdence of Portugal; 52 - Atlas variscids. Buried subsidences: 53 - Algeria-Tunisia; 54 - Adriatic a; 55 - Lebanon - northern Syria; 56 - Dobrudja; 57 - Valachian trough; 58 - Scythian shield; 59 - ranian shield; 60 - Turgai trough; 61 - West Siberian shield; 62 - Uralian folded zone; 63 - vaya Zemlya; 64 - Uralian foredeep.

Alpine folded zone: 65 - Kopet Dag; 66 - Lesser Caucasus; 67 - Zargos; 68 - Greater Caucasus; - Kura and Transcaspian troughs; 70 - Terek-Caspian trough; 71 - Indolo-Kuban trough; 72 - imea; 73 - pontids; 74 - taurids; 75 - Balkans; 76 - hellinids; 77 - dinarids; 78 - Apuseni; 79 - rpathian foredeep; 80 - Carpathians; 81 - Transylvanian trough; 82 - Hungarian trough; 83 - Alps; - Alpine foredeep; 85 - Po River trough; 86 - Ligurian zone; 87 - South Apennines; 88 - Sicily; - Alpine chains of Tunisia and Algeria; 89 - Riff; 90 - Boetian cordillera; 91 - Balearic Islands; - Tyrrhenian massif; 94 - Rhodope massif; 95 - Menderes and Kirshehir massifs; 96 - Dzirul masf; 97 - Salt Desert massif.

Finally, extending from Gibraltar to Iran, thin the Mediterranean and Asis Minor, ere is a complex belt of Alpine folded strucres, the Thetis, a revived geosynclinal sysn on a Paleozoic basement.

East European Platform. Recent studies ve led to a substantial modification of our ncepts of the form, size, and internal strucre of the East European platform. Where boundaries with the adjacent folded strucres are well known, they always consist of ctilinear segments, thus giving an angular tline to the platform. Its boundary has not en established everywhere; this is especially

shield, bound on the east by a meridional trend of the Urals and posthumous uralids, and latitudinally by southern hercinids, has many features in common with its southwestern corner which occupies the northern part of the North German plain from the Oder to the Rhine; the southern part of the Jutlandian peninsula; and the adjacent part of the North Sea. The southwestern corner of the Russian shield is presumably limited in the south by the nearly latitudinal trend of hercinids and caledonids; in the west, by the southwesterly extension of a fringe of the Norwegian caledonids. Thus, there are reasons to believe that Bailey's idea (1928) of an extension of the East European platform as

far as eastern England is not without foundation. This similarity between the southeastern and southwestern corners is due to the fact that these segments of the East European platform have subsided considerably deeper than the rest of it, except, of course, for the Donets-type troughs. The sedimentary section in the southeastern corner (Ural-Emba province) is 10 km or more thick; the Mesozoic, Cenozoic and Upper Paleozoic sequences in the southwestern corner are no less than 5500 or 6000 m thick. Both corners contain major salt provinces. Many facts suggest that these corners were intensively shattered during subsidence: by northeasterly faults in the southeast, and by northwesterly to almost meridional faults in the southwest. On our map, these area, especially the southwestern corner, are represented quite diagrammatically, somewhat better in the southeast. Most probably, the future map of these regions will be quite different, after a comparative study of these structures. We are certain, however, that our representation of the western corner of the platform is more complete than in earlier maps.

An extension of the East European platform north, under the Barents Sea, (Barents shield), is suggested by the following data: 1) the structure of Novaya Zemlya, which is a marginal miogeosynclinal system, indicates the presence of a platform west of it and similar to the Russian shield; 2) the presence of an ancient platform in eastern Spitzbergen, if the interpretation of the tectonics of that island by Norwegian and British geologists is correct; 3) the possible intracontinental trench structure of the Varanger-Rybachiy, Kanin, and Timan belt.

Indeed, the Russian and the Barents shields are separated by a comparatively narrow zone of deformed to locally undisturbed thick Riphean formations that make up the peculiar Timan trench [14] trending northwest.[6] This tectonic zone lies opposite a reentrant in the western corner of the East European platform, quite distinct in the position and change in trend of caledonids of northern Norway and western Spitzbergen. Time of the Timan folding coincides with that of the initiation of the Pachelma trough and possibly that of Greater Donbas. All these elements have the same northwestern linear trend.

As demonstrated by Soviet geologists, the subsidence of the East European platform (since early Riphean time) was accompanied by the formation of a thick mantle. The movement was general, intensified locally in syneclises (such as the Moscow and Baltic) and in special linear troughs well defined by stratigraphic drilling. These linear trenches are narrow, deep, and quite long (hundreds to over a thousand kilometers). They are either simple, canoe-like (e. g., the Pachelma, Kresttsovsk, etc.) to open, wedging out in one direction and plunging in the other, to merge with marginal miogeosynclines. Sedimentary sections in the parts of troughs adjacent to the miogeosynclinal zone are themselves commonly folded in a miogeosynclinal way. Greater Donbas and Timan are examples of such "furrows" (aulacogenes). N. S. Shatskiy believed that the Sventokshisk folded massif is quite similar to the Donbas, in this respect, while the Danish-Polish "furrow" is an analogue of the Greater Donbas simple trench, wedging out to the west. Ancient Archean or Proterozoic rocks, penetrated by drilling under the flat beds southwest of the Sventokshisk Mountains, as well as similar rocks south of the wedging-out Danish segment of the "furrow", corroborate this conclusion. Similar correlations of the Mesozoic Danish-Polish trench with intercontinental geosynclines were previously made by V. Pzharovskiy and Ya. Samsonovich.[7]

The tectonic interpretation of the Baltic shield geology is substantially new (N. Magnusson, A. Simonen, K. Kratz). It is possible that the older age of the svekofennids has not been adequately emphasized. Of interest is the new interpretation of Gothian folding, by N. Magnusson.

Withal, it appears to us that too many purely geologic details have been left in the representation of Precambrian tectonics of the Baltic shield; an impression is created that we know more about it than we really do.

The Erian Platform. A zone of Lewis gneisses of northwestern Scotland and the Hebrides [15], which forms the northeastern foreland of the British caledonids, is taken to be the southwestern margin of a hypothetical Erian platform fully submerged in the North Atlantic. However, the Editorial Board decided against a tectonic differentiation of the Atlantic, within the map; consequently the boundaries of the alleged Erian platform are not indicated. Iceland [16], made up completely of Tertiary and Quaternary volcanic formations, is tentatively included in this submerged platform.

The Canadian shield. The southeastern rim of Greenland, made up of strongly metamorphosed rocks and ancient granites (southwestern Knut Rasmussen Land), is regarded as a foreland of the eastern Greenland caledonids.

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[6]Figures in parentheses are those in the tectonic map (Figure 2).

[7]Intercontinental "furrows" (aulacogenes), identified by N.S. Shatskiy, are shown on both the diagram (Figure 2) and the map, by various symbols (Timan — baykalids; Pachelma trough — a subsidence in the Precambrian platform; Sventokshinsk Mountains — hercinids, etc.), because of the lack of agreement between authors of the map on the nature of these structures.

The African Platform. The northern boundary of the African platform is drawn with adequate certainty along the South Atlas tectonic suture which separates it, over a distance of almost 2000 km, from the Hercinian zone of the Atlas berberids. East of Tunisia, this boundary plunges in the southern part of the Mediterranean and emerges again north of Haifa where it is drawn conditionally along the projected southern edge of the palmyrids.

The Precambrian basement of the African platform is covered by a thick sedimentary mantle, from under which it emerges in a latitudinal system of shields located directly by the lower frame of the map. Reading from west to east, these shields are as follows: Regibat [17], Touareg [18], Gebbou and Arabian [19]. The Regibat shield is made up of ancient series with a generally latitudinal trend. The Precambrian basement also forms small outcrops in the Anti-Atlas [20]; the latter stands out as a peculiar latitudinal uplift complicating the northern margin of the platform. It differs from the adjacent part of the platform in the fairly strong deformation of its Paleozoic mantle, caused mainly by late Paleozoic movements. Branching off to the south of it is a peculiar well-defined zone of flat but long Paleozoic folds (Ougarta zone, [23]), similar to the Russian platform trenches.

Geologic and geophysical studies and drilling in the subsided northern part of the African platform have discovered a number of major uplifts and troughs. In the latter (syneclises Tindouf, [24]; Reggane, [25]; Lower Sahara, [26]; Libyan, [27]), the platform mantle is 3 to 6 km thick; in the uplifts (Tilremt, [21]; Atemada, [22]; etc.) it is reduced to 1.5 to 2 km.

As in other cratons, older deposits of the platform mantle have been deformed in a way different from the Mesozoic types. Paleozoic structure are more complex. They represent local subsidences and a number of uplifts in the crystalline basement, not reflected in the structure of the upper story. The latter, composed of Triassic to Neogene rocks, is characterized by its simplicity; on the whole it is a homocline dipping north, toward the edge of the platform, with the section thickening in the same direction, from a few hundred to 4000-5000 m.

The eastern part of the northern margin of the platform, in Egypt and Israel, is more strongly differentiated. Meridional faults of the Great African Rift system are developed here, besides the gentle subsidences and uplifts common to the northern part of the platform.

We have considered the mantle structure of the African platform in some detail, because of the novelty and great theoretical value of these data obtained by N. N. Menshikov and the geologists of oil companies, as well as by M. Burollet.

Provinces of Caledonian folding. A small outcrop (within the map frame) of caledonids in eastern Greenland [28], outcrops in western Spitzbergen [29], Scandinavia [30], Great Britain and Ireland [31], the Brabant massif [32], and a portion of the central Kazakhstan Paleozoic massif, within the map frame [33] are all within the provinces of Caledonian folding.

Caledonian folded provinces are characterized by a wide development of eugeosynclinal zones, some directly adjoining the Precambrian forelands (Scotland, etc.). Accordingly, their distinctive feature is an extensive development of initial volcanism and of ophiolitic and other volcanic formations. As against the extensive development of basic and ultrabasic intrusions, they are marked by a limited development of postorogenic granitoid intrusions (except in Ireland and Great Britain) and perhaps by a total absence of foredeeps.

The structure of Caledonian folding in Great Britain is represented in great detail, as a result of the study by English and Scottish geologists. The fairly new interpretation of the interior structure of the Scandinavian caledonids is taken from Norwegian and Swedish students. Specifically, all major tectonic nappes and tectonic windows showing the metamorphic basement are indicated on the map.

The Brabant massif is considered as a direct continuation of the British caledonids over the continent. Considerably less clear is the distribution of Caledonian structures in Central Europe. According to Polish and Czech geologists, folded structures of that age, intensively reworked by subsequent Variscian movements, extend east of the Elbe line (Sudeten, etc.); however, their identification on the tectonic map is quite difficult. Evidence of Caledonian folding is present among median massifs of the Variscian folded province, where it is expressed in granitization (central massif of France, etc.).

Provinces of Variscian folding. Incomparably vast expanses of Europe and North Africa are made up of thick geosynclinal Paleozoic and older series of Variscian (Hercinian) folding. They also are present in isolated bodies within the Alpine folded belt. Accordingly, there is every reason to believe that the Variscian folded province took in virtually the entire area between the Precambrian platform of eastern Europe and Africa, and extended westward (southern Ireland, Wales), truncating a comparatively narrow belt of Caledonian folded structures. East of the East European platform, the Variscian folded belt forms meridional

chains of the Urals and Novaya Zemlya and makes up the basement of a considerable segment of the West Siberian shield.

One of the most complex problems in European tectonics, to be solved in a representation of Caledonian and Variscian folding, is the relationship between the ancient platform and Paleozoic folding within the lowlands of Holland, northern Germany, and Poland. A novel treatment of this problem is presented in the map submitted to the Congress. A scheme offered by H. Von Hertner and H. Kelbel was adopted for the west, different from the one adopted for the east. We shall discuss this subject in more detail.

Present in central parts of the Variscian folded province of Western and Central Europe is a number of massifs made up of Proterozoic series and extending in an almost unbroken band from western France to Czechoslovakia (central massif, Vosges, Schwarzwald, Czech massif). These massifs divide the Variscian folded province into almost latitudinal belts.

The northern Variscian belt extends from the south coast of Ireland and northern Brittany, north as far as eastern Poland (Sudeten). Usually included within it are the northwesterly trending Armorican arc (southern Ireland, Cornwall, Brittany, Normandy) and the Variscian arc (properly speaking) with a northeasterly trend (Hercinids, from the east of the central massif of France to the Elbe). Many geologists (S. Bubnoff, H. Stille) believe it possible to identify another small arc formed by the East Sudeten and Sventokshisk massif and connecting the extreme southern and northern hercinids.

These complex relations become fairly simple and understandable if we abandon the hypothesis of a bilateral structure of the northern variscids and accept instead the interpretation of the nature of Sventokshisk Mountains mentioned above. Indeed, in that interpretation, Sventokshisk Mountains are made up of a folded massif in an intercontinental trench, similar to the Donbas and wedging out to the northwest, toward the Danish-Polish trough. Extending southwest of that trench is the same Precambrian platform which is present northeast of it (deep drilling, penetrating the Precambrian underneath the horizontal mantle, in Jutland Peninsula and south of Cracow). This segment of the Precambrian shield, widening to the north, is separated from the variscids by a West Sudeten-type zone of crushing and by a major northwesterly fault (marginal Sudeten normal fault and the Oder normal fault). Such being the case, the Devonian and Lower Carboniferous of east Sudeten, judging from their facies and metamorphism, fill up a folded geosynclinal trough, closed on the south and opening in the north, into a zone of faults along the main scar, at the contact of the variscids and the East European Platform. This is suggested by the lower intensity of metamorphism in the Devonian and Carboniferous section of east Sudeten, going south, and by the appearance here of a Lower Carboniferous transgressive carbonate facies.

Passing through the center of the Czech block, and trending northeast and parallel to the east Sudeten zone, is the "Barrandien" trough, with a closure in the southwest. Strictly speaking, an alternation of uplifted and depressed bands with the same northeasterly trend is also present farther northwest, in the "tectonotype" of Kossmat-Bubnoff's Saxo-Thuringian zone, where they possibly terminate in the same dead end against the faults forming the northern boundaries of the Swabian and North German shields. Some of these bands stand high; e. g., the Mid-German bench, while others are sunken and filled up with non- to slightly metamorphosed sedimentary sections. We shall not go into the complex and, in our opinion, far from clear, relationship between Variscian zones of the Rhine belt, and those of Saxony and Thüringia. We note only that a broad zonal system (from Harz to East Sudeten) of northeasterly trending hercinids has no analogues northeast of the Czech massif. Thus, the entire Hercinian (Variscian) arc, representing a complex Variscian system (Reno-Hercynian and Saxo-Thüringian zones), closes just as completely in the northeast, at the junction with the Russian shield; consequently, it abuts at the cratonic edge in a manner common to folded systems of Eurasia.

It seems to us that hypotheses on an intracratonic position of the Sventokshinsk massif and of the common abutment junction of the Middle European hercinids and the Russian shield provide a good explanation for the complex geologic structure of Central and Eastern Europe.

A feature of this map, perhaps a somewhat new one, is the wide distribution in ancient cores of Franco-Podolia (central massif of France, Vosges, Schwarzwald, Odenwald, Czech massif), of geosynclinal series of the Baykalian (Assyntian, Cadomian) folding, mostly of a eugeosynclinal type. The trends of ancient folds vary in a broad range, in different massifs, some becoming meridional (as in the central massif of France). Such an extensive development of Cadomian (Assyntian, Baykalian) folding in Middle Europe suggests that these ancient cores are newly formed folded bodies, newly consolidated zones, rather than residual blocks left behind intact during the formation and subsidence of the Neogene megachron geosynclinal systems. If this is true, the very idea of Franco-Podoliz should be abandoned.[8] However,

[8]See article by Ye.V. Pavlovskiy, "Stages of Geosynclinal Development of Hercinian massifs of France and Southern Germany". (Izv. Akad. Nauk U.S.S.R., ser. geol., No. 11, 1960.)

N. S. Shatskiy persists in believing that the general configuration of these ancient massifs, and particularly the Riphean history of the crust, rather support S. Bubnoff's old concept.

All median massifs have been reworked by Variscian folding expressed in tectonic deformations, metamorphism, and granite intrusions. Marginal parts of some of those massifs (Brittany, Moravan, Cevennes, northern Vosges, etc.) have been regenerated, partially to almost completely, in the evolution of a Paleozoic geosynclinal area, so that the features of their ancient history are barely discernible.

The Variscian belt south of a zone of median massifs and embracing the folded Paleozoic structures of the Iberian Peninsula, the axial part of the Pyrenees, southern France, Corsica, Sardinia, the Paleozoic cores of ancient median massifs of the Alpine folded belt, etc. are fairly well delineated on the map; Paleozoic formations on the southern fringe of the East European platform and the northern part of the Sahara shield are also well delineated. We have no doubt that our map will be of some assistance in solving the complex problem of Paleozoic structures and the Paleozoic stage of development of the Alpine folded zone.

That immense area is marked by great heterogeneity of structure. It contains zones of different development, different age of folding, and variable trends. The isolation of the outcrops of individual massifs, along with the uneven status of their study, makes it impossible to map all the relationships between the links of this chain.

Variscian folded formations of the northern and southern belts, outside the superimposed Alpine geosynclinal system, are overlain in many places by an epi-Paleozoic platform mantle. In Western Europe, this mantle fills up isolated major troughs, such as the Paris [48] and Aquitanian [49], basins where the thickness of slightly disturbed and nonmetamorphosed Permian, Mesozoic, and Cenozoic sediments attains several kilometers. The form and structure of some of these troughs are well delineated by structure contours on the tectonic map of Europe. The platform mantle of African variscids has been affected fairly strongly and extensively by Alpine block movements.

Finally, tectonic data on the Urals and the epi-Paleozoic platform mantle within the West Siberian [61] and Turanian [59] shields, have been substantially revised for the purposes of this map.

The Alpine folded province extends in a series of intricate sinuous branches, latitudinally within the map area, from Gibraltar to Iran. As pointed out before, the Alpine folded structures of Europe, North Africa, and Asia Minor represent a superimposed geosynclinal system which formed at the site of an earlier Paleozoic (largely Variscian) folded province. The Paleozoic basement is exposed along the axial part of the Alpine trend, as a system of median massifs, such as the Calabrian [93], Rhodope [94], etc. ; also in the cores of geanticlinal uplifts forming rosary-like zones (Paleozoic cores of Liguria, massifs of Argentère, Pelvoux, Mont Blanc, etc.).

The Pyrenees occupy a place of their own in the Alpine system of Europe, because of the lack of their visible direct connection with the main body of Alpine folds. These mountains appear to be an isolated geosynclinal trough which developed in the Paleozoic basement, simultaneously with the Alpine folded province. We have speculated on the possibility of the entire West Mediterranean Alpine zone being a similar isolated zone. However, the most detailed synthesis of the tectonics of that area, by P. Fallot, fails to provide a definite solution of this problem. We have no doubt that such a breaking up of the Alpine province into isolated (closed) troughs could be brought into accord with the general westerly wedging out of the Alpine structures.

Mio- and eu-geosynclinal belts are clearly distinguishable within the Alpine province, with the standard regularity prevailing in their distribution; the outer zones are predominantly miogeosynclinal while the inner zones are eugeosynclinal. The inner zones are associated, as a rule, with central parts of the Alpine fold provinces where they are extensively developed in the eastern part of the area in question. They form the bulk of Iranian, Turkish, and Balkan folded complexes (hellenids, [76]; dinarids, [77]), extend into the Alps (Pennine zone) and into the Tyrrhenian Sea, cropping out on the Ligurian coast [86] and in eastern Corsica. Farther to the west, the eugeosynclinal zone appears to wedge out. Instead, the west Alpine zone is characterized by miogeosynclinal conditions, reflected in the Rift folding [90], the Alpine chains of northern Algeria and Tunisia [89], the Boetian cordillera [91], and Balearic Islands [92]. Within the Alps and the Carpathian arc, the miogeosynclinal zones are displaced toward the northern rim of the province; in the east, they are present virtually only in the Crimea [72], Greater Caucasus [68], and Kopet-Dag [65]. Marginal troughs filled with Neogene molasse are well developed along the periphery of the Alpine province.

The Alpine folding of Europe is marked by extremely intensive deformation, with nappes widely developed in the western part (Alps, Boetian cordillera, North Africa, etc.). It is quite probable that many of these nappes are gravity deformations. However, our map shows

that the regular and conventional structure of a folded zone prevails even where the nappes are best developed. Thus, the western part of the Alpine zone exhibits an excellently developed central eugeosynclinal zone fringed on the north by a chain of uplifted ancient massifs, a miogeosynclinal zone, and a marginal trough. Miogeosynclinal folded formations are once more developed south of the eugeosyncline. Thus, the nappes do not disturb the general regularities ordinarily recurring in all folded zones, and first of all in those without any nappes. This suggests that the nappes are not a principal structural feature but rather a detail, a particular expression of the tectonic style.

We are certain that further work on the tectonic map of Europe will solve this complex problem of the Paleozoic structure of the Alpine zone, a necessary step toward determining the fole of inheritance in the development of various tectonic zones in the formation of the Alpine geosyncline and in the mergence of this structurally amazing folded system.

* * *

The first international tectonic map of Europe and adjacent lands has been created as the result of an intensive three-year long period of work by a large group of European geologists. To be sure, it has numerous and substantial shortcomings. As we have pointed out, many important problems were formulated in the course of its compilation, but not all of them have been successfully solved. A number of other problems were merely outlined, subject to further consideration. It is possible that some new data have not been taken into account, particularly drilling and geophysical data; however, most of the data extant on the geology of this continent have been utilized by the authors

Despite all its shortcomings, this map constitutes, in our opinion, a substantial contribution to geology. We hope that it will find its place, in the near future, in all classrooms of geology and in geologic institutions of Europe and will be extensively used in geologic researc and instruction as well as in applied geology.

It is perhaps expedient to start work on the second edition of this map, by taking advantage of the experience gained and of the extended study; also to prepare the ground for a symposium on the tectonics of Europe, the urgency of which is obvious.

Work on the tectonic map of Europe has clearly demonstrated the great value of such collective studies. Assembled around a conference table, geologists of most diverse schools worked for a convergence of their ideas in the most important problems in geology, striving for currect solutions, satisfactory to all. This climate of cooperation and of maximum mutual understanding was typical of all work on the first international map of Europe. It was the pledge of success in this great and complex undertaking.

Commission on "Geotectonic Maps"
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TRANSVERSE FAULTS CONTEMPORANEOUS WITH SEDIMENTATION AT THE CENTRAL AND WESTERN BOUNDARIES OF THE CAUCASUS, AND THE DISTRIBUTION OF MESOZOIC AND CENOZOIC FACIES

by

V. Ye. Khain and M. G. Lomize

GENERAL CONSIDERATIONS

While participating in the Caucasian expedition of Moscow University from 1955 to 1958, we studied the Pshekha-Belaya watershed area in the northern Caucasus, which coincides geologically with the central western Caucasus boundary and is characterized by an abrupt west-east change of facies in the Mesozoic and Cenozoic sequences, beginning especially with the Upper Jurassic. The general stratigraphy of that region was determined by I. I. Nikshich and O. S. Vyalov [16] but the work that did most to clarify its structure and geologic history was that of V. V. Belousov, partly in cooperation with B. M. Troshikhin [3].

V. V. Belousov was first to notice the unusually rapid changes in Upper Jurassic and Lower Cretaceous facies and thicknesses, in the area between Belaya and Pshekh Rivers, and to illustrate it with stratigraphic maps and cross sections. He associated these changes with the transition from his newly-discovered northwestern Caucasian geanticline to the main Caucasian geosynclines; in so doing, he did not attach any particular importance to the fact that the boundaries of facies and thicknesses here trend almost meridionally, normal to the prevailing trend of structural zones. Nor did he perceive the connection between the facies he identified and meridional faults which he had drawn on the map (compiled in cooperation with B. M. Troshikhin). B. M. Keller [9] and N. P. Luppov [13], who studied the Cretaceous in the western Caucasus, likewise supposed that the abrupt changes in the composition and thickness of deposits south of Belaya River had been determined by a longitudinal tectonic zone.

This article is an attempt to refine V. V. Belousov's picture of facies changes in the Upper Jurassic deposits, on the basis of new material, and to demonstrate its connection with movements along faults transverse to the general Caucasian structure and constituting on the whole a zone separating the western and central Caucasus. Of particular interest is the presence in this zone of large Oxfordian-Tithonian reef bodies which escaped the attention of V. V. Belousov but had been noted earlier by N. Morozov [14], the first student of the Fisht-Oshten mountain group. We also will attempt to show that these transverse faults persisted into post-Jurassic time, up to the Anthropogene, with periods of quiescence and revived activity. Deposits dated as Upper Jurassic through Paleogene along this zone, range from normal neritic to deeper flysch. It follows that the northwestern Caucasian flysch trough was limited in the east by a zone of transverse faults. A correlation of thicknesses for the flysch and non-flysch Upper Jurassic deposits shows that the subsidence was not fully dompensated by sedimentation at early stages.

The regularities which we have determined in that part of the Caucasus undoubtedly hold true in a more general sense and shed light on certain features of geosynclinal sedimentation as a whole.

Latitudinal tectonic zonation prevailed throughout the Caucasus, in the early and middle Jurassic. It was associated with the activity of faults of the same trend, although a transverse zonation was also present. As in subsequent epochs, the Central Caucasus was characterized by its relatively high elevations. Only Toarcian-Bajocian marine deposits are known here; and the sediments are many times thinner than in the western and eastern Caucasus. However, the western boundary of that transverse uplift did not pass along the zone of cross faults described below but rather along a more easterly escarpment, east of the Urup River. It is here that marine deposits of the Lotharingian, Plinsbachian, and Domerian stages are seen to wedge out.

There was a change in the structural plan, following the pre-Callovian phase of block-folding movements, with a transverse tectonic zonation gaining in importance. Beginning with the Callovian, two major structural facies zones

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[1] Poperechnyye konsedimentatsionnyye razlomy na granitse Tsentral'nogo i Zapadnogo Kavkaza i raspredeleniye fatsiy mezozoya i kaynozoya.

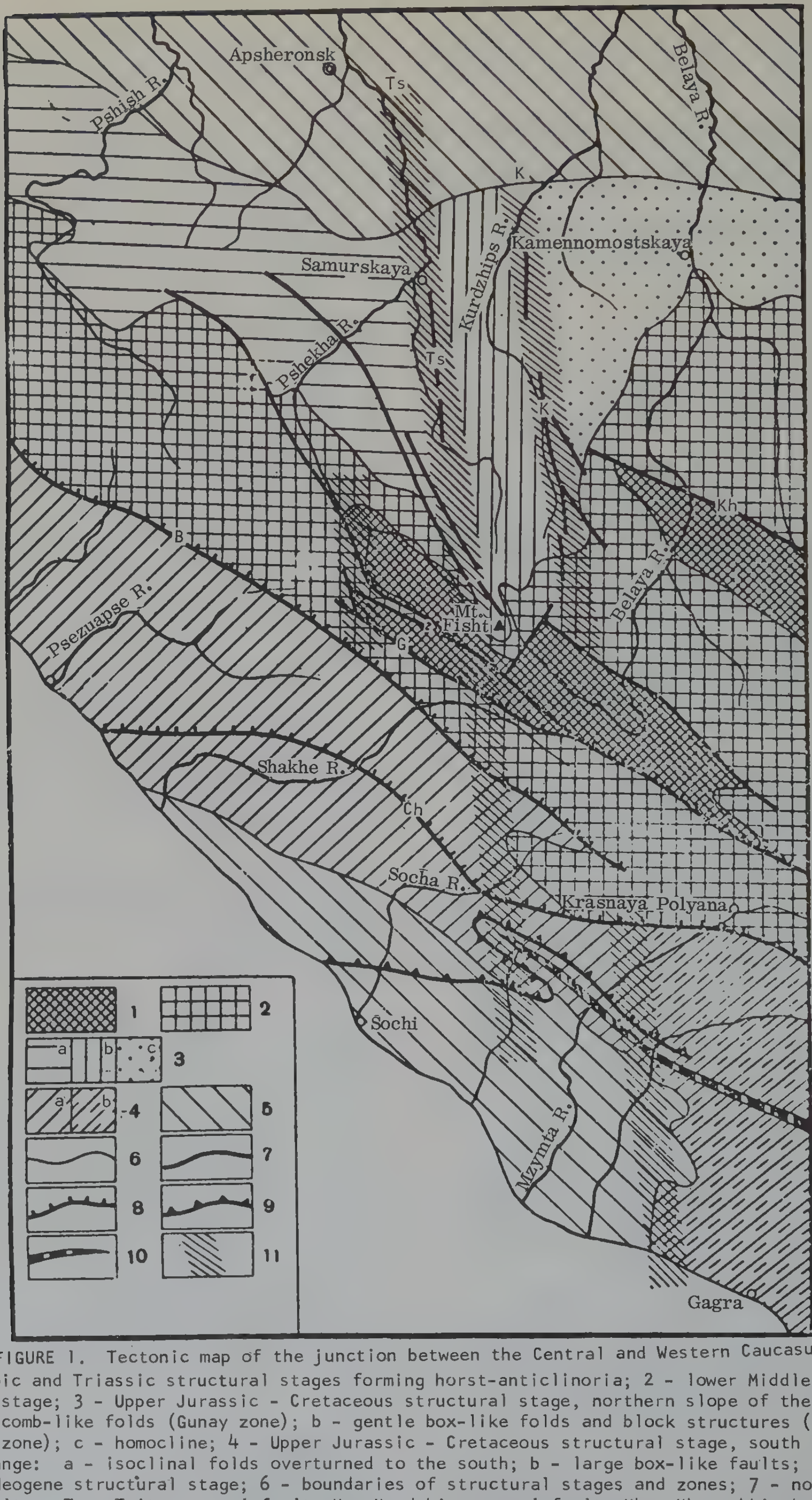

FIGURE 1. Tectonic map of the junction between the Central and Western Caucasus

1 - Paleozoic and Triassic structural stages forming horst-anticlinoria; 2 - lower Middle Jurassic structural stage; 3 - Upper Jurassic - Cretaceous structural stage, northern slope of the Main Range; a - comb-like folds (Gunay zone); b - gentle box-like folds and block structures (Lagonak transition zone); c - homocline; 4 - Upper Jurassic - Cretaceous structural stage, south slope of the Main Range: a - isoclinal folds overturned to the south; b - large box-like faults; 5 - Paleogene-Neogene structural stage; 6 - boundaries of structural stages and zones; 7 - normal and reverse faults: Ts - Tsitsa normal fault; K - Kurdzhips normal fault; Kh - Khamyshkinsk reverse fault; 8 - overthrusts: G - Main; B - Bekisheysk; Ch - Chemitokvadzhinsk; 9 - Vorontsov nappe; 10 - axis of the Akhtsu uplift; 11 - zones of major transverse faults: Ts - Tsitsa; K - Kurdzhips.

emerge within the northwestern Caucasus: the eastern (the Belaya basin and east of there; this corresponds to the province of the north Caucasian homocline) and the western or Gunay zone (the Pshekha River basin and west of there); they are separated by a comparatively narrow Lagonak transition zone extending north-south, from Mt. Fisht along the valleys of Tsitsa and Kurdzhips Rivers (Figure 1). The formation of shallow water arenaceous and argillaceous deposits of the eastern zone was accompanied by deposition of thick calcareous terrigenous flysch in the western zone. The facies zonation was most conspicuous in the Kimeridgian (Kimmeridgian) and Tithonian (Figure 2).

FACIAL CHANGES IN THE KIMERIDGIAN AND TITHONIAN DEPOSITS

Northwestern Caucasian Kimeridgian and Tithonian deposits have not been differentiated and are considered here as a whole.

In the eastern zone (in the Belaya valley and east of there), these deposits are represented, according to the data of I.I. Nikshich, M.G. Barkovskaya, and the present authors, by motley argillaceous sandstone with beds of fine-pebble conglomerate, a total thickness of about 420 m, resting on an uneven karst surface of Oxfordian limestone. The lower motley horizons

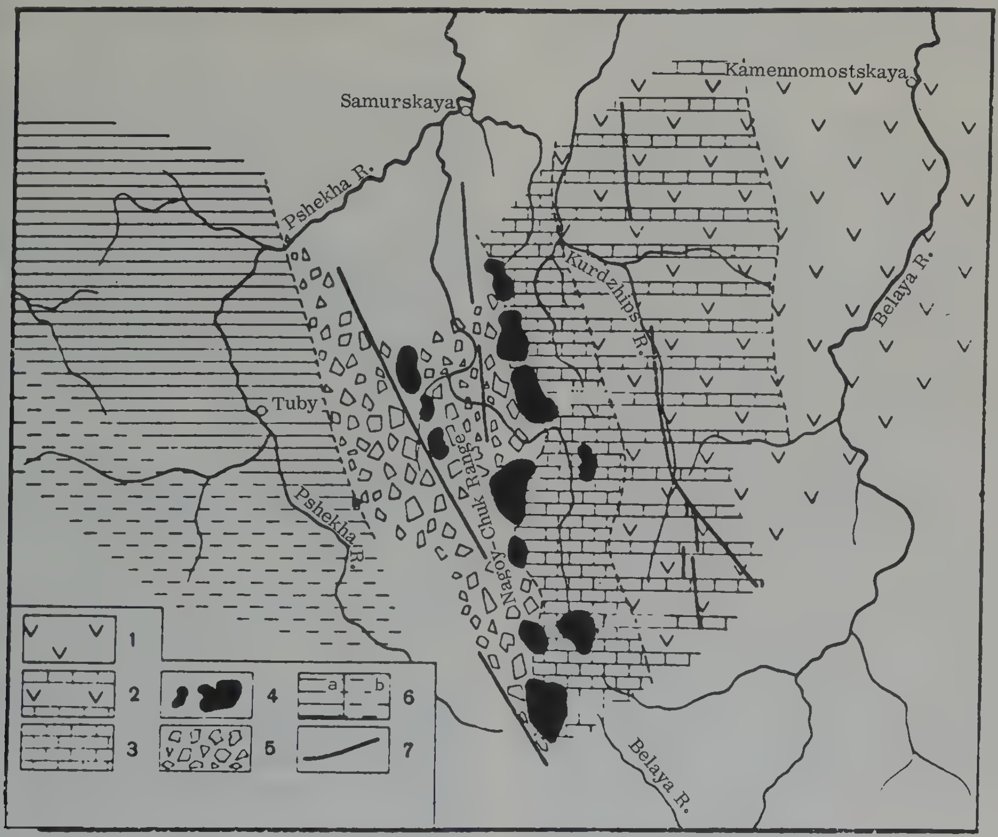

FIGURE 2. Distribution of Kimeridgian and Tithonian facies in the basins of Belaya and Pshekha Rivers.

1 - Mottled sandstone and shale, gypsum; 2 - mottled shale with intercalations of oölitic limestone; 3 - organic clastic, oncolitic to oölitic limestone; 4 - reef massifs; 5 - limestone breccia and conglomerate-breccia; 6 - shales interbedded with calcareous-sideritic gravel beds (flysch): a - known distribution; b - assumed distribution; 7 - faults.

carry lenses and intercalations of gypsum, especially numerous east of the Belaya. The age of this motley section is established approximately, from its stratigraphic position between the fossiliferous Oxfordian and Valanginian beds. The composition of the Kimeridgian-Tithonian deposits, along with the presence of ripple marks and cross-stratification in sandstones, as well as plant detritus and a brackish-water fauna (Planorbis sp., etc.), indicate that the deposition took place in a shallow basin isolated from the sea (i.e., in a lagoon).

In the western zone, along the Pshekha and west of there, Kimeridgian and Tithonian stages are represented by a flysch facies of blue-gray calcareous shale and marl with beds of calcareous gravel and polymictic calcareous sandstones. The clastic rocks exhibit typical transitional flysch textures, with hieroglyph casts at the base of initial elements of the rhythm. The age of the flysch section is determined from its stratigraphic position and from the microfauna: Lagenahispida Reuss., Lenticulina magna Mjatl., L. Rotulata. (Corn.), L. lata (Corn.), Pseudoglandulina tutkovskii Mjatl., Sarasentaria italica (Defrance), Vaginulina raricostata Furs. et Rel., Nodosaria radicula Linn., Spirillina ex gr. elliptica Küb. et Zw., Dentaline communis Orb., Conicospirillina jarassica Kapt. -Tshern., etc. (Foraminifera from our collection were identified by Ye. A. Hofman; ammonites by G. A. Loginova; corals by N. S. Bendukidze; brachiopods by K. Sh. Nutsubidze; gastropods by S. S. Kostyuchenko.) In addition, according to V. G. Pas'ko (Krasnodarnefterazvedka Trust), Virgatosphinctes densiplicatus Waag. and Chlamys polycycla Blaschke have been identified in shale along Pshekha River, south of Volch'i Vorota I. Kimeridgian-Tithonian deposits along Pshekha River are 300 to 350 m thick.

The change from eastern (motley lagunal) to western (flysch) Kimeridgian-Tithonian facies takes place within the Lagonak transition zone. In the Kurdzhips basin, west of the Belaya, sandstone of the motley section is replaced by shale and dolomitic marl interbedded with argillaceous limestone. On the left bank of the Kurdzhips, the calcareous beds are more numerous, with the appearance of oölitic, calcarenitic, and organic varieties, including foraminiferal (largely of genera Spirophtalmidium, Lenticulina, Nodosaria).

At the same time, the upper and lower horizons of this section are completely replaced by limestone. A lower limestone member, about 35 m thick, is exposed in the Kurdzhips headwaters where it is represented largely by stratified oölitic limestone with some motley dolomite. An upper member, about 200 m thick, crops out in the area of Temnolesskoye settlement, on the Memzay River; it crosses the Kurdzhips valley in the Guam gorge, and makes up the upper reaches of the left slope of the Kurdzhips valley (Memzay, Abadzesh summits, etc.). The most common limestones are calcarenitic, organic and oölitic varieties. Small oyster bioherms have been observed in Mt. Abadzesh. The total thickness of the Kimeridgian-Tithonian stage in the Kurdzhips basin reaches 500 m.

Ammonite Plachyplanulites subevolutus Waag., typical of the Kimeridgian stage, has been identified by G. A. Loginova (Moscow University), from motley shales near the village of Memzay, while Subplanites contiguus Cat. has been identified in the upper member limestones in Mt. Abadzesh. A. M. Makhneyev (Krasnodarnefterazvedka Trust) has identified the following from the same member in Mt. Memzay: Virgatosphinctes densiplicatus Waag., Aucella russiensis Pavl., A. mosquensis Buch., Astrate pontica Pčel., Natica cf. crimica Pčel., and Planeroptyxis kokkosensis Vogti. We have identified corals Thecosmilia trichotoma Münst. from the upper member limestone in Mt. Lenin. Thus, the faunal findings corroborate the Kimeridgian-Tithonian age of these deposits.

In the Kurdzhips-Tsitsa watershed, west of the Kurdzhips, Kimeridgian-Tithonian motley arenaceous-argillaceous deposits, over a distance of 2.5 to 3 km, are completely replaced by 550 to 600 m of limestone exposed in the Tsitsa gorge (upper course); in the east slope of Mt. Oshten; and in the Lagonak Range, east of Mt. Zhitnaya. Developed here are stratified calcarenitic and oncolitic to oölitic limestone and limestone breccia; to the west, they change to massive reef bioherms of Oshten, Nagoy-Chuk, and the Lagonak Range. In many places, the beds are marked by their primary dips (up to 20°) as they wrap around the reef masses.

Detrital organic limestones of this section consist largely of coral fragments, blue-green and red calcareous algae, calcareous sponges, echinoids, brachiopods, pelecypods, and gastropods. Also present are coarse detrital varieties with oncolites and intact gastropod shells (Nerinea, Ptygmatis, etc.). Clastic material in organic limestones is appreciably rounded and granulated (particularly so at the grain surface); in addition, there are calcareous oncolites, oölites, and foraminifera tests. Commonly present are large (7 to 10 cm) nodules of calcareous algae. Many varieties of clastic limestone have a fine stratification and carry some argillaceous and polymictic silty material.

Oncolitic limestones occur largely in the lower half of the section, with the oncolites reaching 2 to 10 mm in diameter. As a rule, they show evidence of rounding, previous to burial, with occasional traces of boring algae.

These limestones, present in subordinate amounts, usually carry an addition of calcarenitic and terrigenous arenaceous material.

Limestone breccias of this section, fine to medium-coarse, are made up of angular to semirounded fragments of coral, algal, oolitic, and detrital limestone. Thus their composition, like that of the calcarenitic limestone, suggests that much of the clastic material came apparently from reef massifs to the west.

G. A. Loginova has collected a typical Kimeridgian Simoceras cf. favaraensis Gemm., in the slope of the Nagoy-Chuk Range, 200 to 250 m above the base of stratified limestones. In the same locality, as well as in the underlying interval, we have collected the following corals: Calamophyllia virgulina Etall., C. flabellum Blainy., Thamnoseris amedei Etall., Latimaendra greslyi Koby, Stylina (Convexastraea) minima Etall., S. (C.) semiradiata Etall., Latimaeandra thurmani Edw. et Haime, and Stylosmilia michelini Edw. et Haime. The finding of these last three forms may indicate an Oxfordian age[2] for lower horizons of the stratified limestones. Gastropods are abundant in the upper part of the section; among them are Cryptoplocus consorbinus Zitt., Nerinea hohenggeri Peters, Ptygmatis carpathica Zeuchner, P. Pseudobruntrutana, indicating the Tithonian age of these beds. Also identified in the upper part of this section, on the east slope of Mt. Oshten, have been Phaneroptyxis robinsoni Pčel. and coral Thamnoseris amedei Etall.

This area of stratified limestones is bound on the west by a chain of large reef masses extending from Mt. Fisht in the south to the Nagoy-Chuk Range and eventually the Lagonak Range (Figure 2). The lower part of the Mt. Fisht massif, one of the largest, is made up of white massive bioherm limestones (mainly coral), considerably recrystallized. Calcarenitic limestones with nodules of blue-green and red calcareous algae are present along with the bioherms. The coral and algal bioherm limestones, yellow-gray to red, continue upward, to the mountain top. Areas of limestones consisting of intact brachiopod shells have also been observed. The over-all height of the Mt. Fisht reef mass is 800 to 850 m. Its lower interval carries corals Stylina (Convexastraea) minima Etall.; the middle part — Rhipidogyra flabellium Michelin and Pachygyra choffati Koby. Collected at the top of Mt. Fisht have been Thecosmilia magma Thurm., Montivaultia truncata Edw. et Haime, and Terebratula kokkosensis Moiss.

All these forms are typical of the Upper Jurassic, while some of them, including the last ones, are known mostly from Lusitanian deposits. Nevertheless, considering the great thickness of these bioherm limestones and their spatial association with Kimeridgian-Tithonian stratified limestones (of which more is said below), it may be assumed that the upper interval of the Mt. Fisht reef body is Kimeridgian and perhaps Lower Tithonian.

The Mt. Oshten reef mass is located 2 km northwest of Mt. Fisht. Its lower and middle parts are made up of red bioherm (coral, less commonly algal) and calcarenitic limestones consisting of fragments of corals, algae, brachiopods, pelecypods, and echinoids. Finely detrital limestones with a small addition of argillaceous material also fill up the space between individual corals in bioherm limestones. The upper part of the reef body, as far up as the top of Mt. Oshten, consists of yellow-gray massive calcarenitic limestones and those made up of intact brachiopod shells, with individual bioherms of corals and blue-green algae. The Mt. Oshten reef body is 750 to 800 m high. Present at its base, on the south slope, are corals Myriophyllia angustata Orb., M. cf. thurmani Etall., and Microsolene coesaris Etall., with Heliocoenia aff. coralina Koby at the base of its eastern slope; they all suggest rather an Oxfordian age for the enclosing rocks. Present higher in the section, in red bioherm limestones exposed on the north slope of Mt. Oshten, are Stylosmilia cf. subvica Becker, S. cf. rugosa Becker, Calamophyllia etalloni Koby, and Heliocoenia humberti Etall., all typical of the Kimeridgian, with some of them also typical of the Tithonian. The overlying brachiopod and calcarenitic limestones are tentatively assigned to the Tithonian, although their brachiopods belong, according to K. Sh. Nutsubidze, to the species Terebratula kokkosensis Moiss. and are known from Lusitanian deposits.

The Mt. Pshekha-Su reef mass, adjacent to the Oshten, has a similar structure. Extending farther to the north is a large reef body of the Nagoy-Chuk Range, exposed on its northern and western slopes. Only the upper part of the reef is exposed and is seen to consist of massive yellow-gray algal limestones. Calcite, which fills up cavities among the algal structures, forms crustification fringes typical of bioherm structures. There are subordinate coral, oyster, and calcarenitic limestones with shells of gastropods and brachiopods and with remains of echinoids and crinoids.

From the Nagoy-Chuk Range, the main chain of reef masses extends north, along the Lagonak

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[2]In accordance with views of V.F. Pchelintsev [18] and with resolution of the Conference on Mesozoic Stratigraphy of the Southern U.S.S.R. (1958), we have designated the Lusitanian as an Upper Oxfordian substage.

Range. However, the reef bodies are exposed here only locally, being buried under limestone breccias and stratified calcarenitic limestones which wrap around their western slopes (toward the Tsitsa valley). Corals Thamnasteria confluens Quenst., known from Kimeridgian-Tithonian deposits, have been identified near the top of one of these masses. Exposed farther north, in ravines on the right side of the Tsitsa valley, in the Mt. Bukv area, is the upper part of a reef made up of massive bioherm (coral and algal) and calcarenitic limestones with inclusions of oncolitic limestones, nodules of calcareous algae, and whole shells of pelecypods and brachiopods.

A second chain of reef massifs lies to the west, extending north-northwest of the Nagoy-Chuk Range toward Mt. Messo and farther on to the Kuzha-Cheshcha watershed. Mt. Messo itself is made up of yellow-gray, massive organoclastic, and bioherm limestones, less commonly by coral limestones. Detrital limestones in the upper part carry numerous large gastropod shells, with Cryptoplocus consorbinus Zitt., Nerinea defrancei var. posthuma Zitt., Ptygmatis carpathica Zeusch., and P. Pseudobruntrutana Gemm., identified among them. Most of these forms are typical of the Tithonian.

Developed between the reef massifs are well-stratified organoclastic, oncolitic, and oölitic limestones and limestone breccias similar to those described from the Tsitsa gorge. Well exposed in the Belaya headwaters are stratified limestones between the massifs of Mt. Fisht and Mt. Pshekha-Su. Their beds dip gently (up to 15°) into the trough; going toward the reefs, they are gradually replaced, first by thick-bedded and coarsely-clastic and then by massive bioherm limestones, up to 550 m thick. A fragment of Stylina cf. tenax Etall. coral has been found in their lower part.

Present in the middle Tsitsa course, between two reef ridges — of the Lagonak Range in the east and Mt. Messo in the west — there was a deep north-trending trough, about 3.5 km wide. It was closed in the south, in the area of the Nagoy-Chuk north slope. Trains of red to yellow-gray limestone breccias were descedning the surrounding reef massifs; they came to rest with the original dip toward the middle of the valley (from due west to N — 60° — W, at 10-15°, on western slopes of the Lagonak Range; N — 10-35° — W, at 15-20°, on northern slopes of the Nagoy-Chuk Range). They thin down rapidly, in the same direction, to 60-80 m in the lower course of the Serebryachka River. The Tsitsa valley, subsequently filled up with Hauterivian and Barrhemian shales, has been reconstructed by erosion and is well expressed in present day relief.

West of the Fisht-Messo-Lagonak reef massif belt, the Kimeridgian and Tithonian are represented by limestone breccias, medium- to coarse-clastic and blocky, yellow-gray to red. Appearing first in western slopes of massifs Fisht and Pshekha-Su, as well as in the Serebryachka headwaters, these breccias are traceable westward along the Chernogor'ye line, as far as Pshekha River. They thin down to 250 to 300 m, in the same direction, while their material becomes coarser. In the upper course of Chesha River (right tributary of the Pshekha), beds of terrigenous flysch appear among them and thicken westward. This facies replacement of breccia by flysch is complete in the Pshekha valley; west of there, the Kimeridgian-Tithonian is represented by flysch, as described above.

Kimeridgian-Tithonian limestone breccia consists of fragments of coral, algal, oncolitic, and oölitic limestones, as well as calcarenitic types with fairly common whole shells of Nerinea, Ptygmatic, and other gastropods. Within the Chernogor'ye area and in the upper part of its western cliffs (above Oxfordian "red breccias"), corals have been picked out of limestone fragments, typical mainly of the Kimeridgian and Tithonian: Rabdophyllia disputabilis Becker, Dimprphocoenia cf. confluens Quenst., Polyphylloseris cf. ramos Ogilvie, Calamophyllia etalloni Koby, C. cf. flabellum Blainv., Thamnasteria cf. oculata Koby, and Ptychochaetetes globosus Koechlin. Thus, the formation of coralline limestones and their redeposition as breccia were separated by a short time interval (within the same age). That, and also the composition and form of the clastic material, as well as the spatial distribution of these limestone breccias, makes it possible to regard them as synchronous with the Lagonsk zone reefs and formed on the western (toward the flysch trough) slopes of reef masses and at their base.

In summing up the description of facies changes in Kimeridgian-Tithonian deposits of the northwestern Caucasus, the following features can be noted. The change from eastern (motley lagunal) to western (marine flysch) facies occurs over a distance of 12 to 13 km within the Lagonak transition zone. From east to west, arenaceous-argillaceous motley beds are gradually replaced, first by limestone; west of the Tsitsa basin, the limestone is rapidly replaced by calcareous-terrigenous flysch, with a bathymetrically expressed escarpment obviously present along the submeridional boundary of facies zones. A ridge of reef masses extended along the upper edge of that escarpment, while its western (downthrown) side was the bottom of a flysch trough. A train of limestone breccias was formed along the western slopes of the reef ridge and at its base.

FACIES CHANGES IN CALLOVIAN AND OXFORDIAN DEPOSITS

As pointed out above, the transverse structural facies zonation in northwestern Caucasus, as illustrated in the Kimeridgian and Tithonian stages, was underway as early as the Callovian.

Everywhere in the area in question, Callovian deposits rest on the underlying rocks with a break and an angular unconformity. In the eastern zone (the Belaya basin), during the Callovian, the shallow-water sands, sandy shale, and limestone were deposited with a total thickness of not over 60 m. The callovian is represented here by all three stages; the lower substage is characterized by ammonites Dinolytoceras cf. adelae Orb, and Macrocephalites pila Nik.; the middle, by Hectioceras pseudopunctatum Lah., H. pavlowi Tsyt., H. lanula Ziet., H. metomphalum Bonar, H. salvadori Par. et Bonar., Perisphinctes mosquensis Fisch., P. rjasabensis Teiss., P. submatatus Nik., Reineckeia cf. plana Lič., R. anceps Bayle, Quenstedticeras cf. brasili Douv., and Erymnoceras cf. coronatum Brug.; and the upper, by Pèrisphinctes cf. subtilis Neum., Cosmoceras transitionis Nik., Partshiceras viator Orb., and Ptychoohylloceras hommairei Orb.

To the west, sandy Callovian lithofacies are traceable as far as the right bank of the Tsitsa River. West of there, their composition changes rapidly, being represented in the Pshekha basin by a thick (over 400 m) flysch section of greenish-gray shale with calcareous sideritic gravel beds. Their Callovian age was determined by their stratigraphic position as well as by findings of foraminifera: Lenticulina praerussiansis (Mjatl.), L. ovato-acuminata Wisn., L. erucaeformus Wisn., L. hoplites Wisn., Spirillina kübleri Mjatl., Epistomina conica Terq., E. stelligeraeformis Mjatl., and Lagena helvetica Küb. et Zw.

Thus, as early as the Callovian, the eastern zone was characterized by a relative uplift and low mobility, while the western became a flysch trough. The boundary of structural facies zones extended submeridionally in the Tsitsa-Pshekha watershed; i.e., in the western part of the Lagonak zone.

The distribution of Lower and Middle Callovian lithofacies and thicknesses in the western zone was affected also by an inherited development of longitudinal elements of the pre-Callovian structure. The buried Dakhnov and Rufabgo horst anticlines are associated with sandy facies and small thicknesses (6 to 10 m), while the troughs between them are marked by argillaceous facies of maximum thickness (40 to 60 m). The Upper Callovian alone, which rests here erosionally on the Middle Callovian and forms a unit with the Oxfordian limestone, does not exhibit any effect of longitudinal tectonic zonation, being marked by a uniform composition and thickness. In the western zone, with its comparatively rapid accumulation of a thick flysch section, there is no effect of a longitudinal tectonic zonation, even in lower Callovian beds.

Limestone lithofacies spread widely, beginning with the Oxfordian. Formed at that time under the epicontinental shallow-water conditions of the vast eastern zone were monotonous organic and calcarenitic limestones, massive to thick bedded, with cherty concretions. They are 50 m thick, at Kamennomostskaya station, and 90 to 100 m in the Kamennoye More Range. The Oxfordian age of these limestones is established from V. N. Robinson's findings (1944) of ammonites along the Malaya Laba: Peltoceras cf. arduunens Orb., Perisphinctes bernensis Lor., P. consociatus Buckm., P. cf. tizianiformis Choff., and P. pekatilis Orb.

In the Lagonak transition zone, the thickness of Oxfordian limestones increases to 200 or 250 m; bioherm varieties (mainly coral) also appear there. Kimeridgian-Tithonian stratified calcarenitic to oncolite limestones are underlain here by massive bioherms and calcarenitic limestones. The following corals have been collected in them, south of Mt. Abadzesh: Montivaulitia truncata Edw. et Haime, Thecosmilia cf. znnularis Edw. et Haime; at the Belaya headwaters, Dermoseris plicata Koby, Epistreptophyllum excelsa Koby, Thecosmilia magna Thurm., Calamophyllia flabellum Blainv., Stylina (Convexastraea) semiradiata Etall. In addition, as pointed out before, during the Oxfordian, the lower parts of the Fisht, Oshten, and other reef masses were formed, although they probably did not represent isolated reef bodies, at that time, inasmuch as the accumulation of reef limestones took place throughout the Lagonak zone area.

West of the Lagonak zone, reef limestones are replaced by limestone breccias which thin westward, down to 200 m in the Chernogor'ye and to 160 m along Pshekha River. Calcareous and conglomerate breccias are most commonly red. They were first described as "red breccias", by I. I. Nikshich and O. S. Vyalov [16]. The breccia fragments are represented largely by coral (Figure 3), brachiopod, and calcarenitic limestones carrying Cladofyllia aff. miroi Felix, Dimorphastraea radschensis Bend., Ptychochaetetes globosus Koechlin, Zeilleria ex gr. immanis Zeusch., Terebratula haasi Roll., Rhynconella cf. pinquis Roemer, and R. cf. corallina Leym. There forms are characteristic of the Oxfordian, more specifically the Lusitanian, deposits of the Mediterranean province. Shale beds among the red breccia carry the foraminifera Trochalina nidiformis (Brück.), T. transversarii (Paal.), Lenticulina

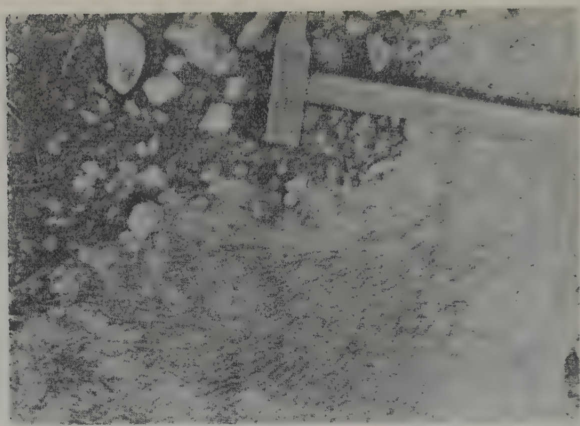

FIGURE 3. Fragment of a coral colony in red Oxfordian breccia. Chernogor'ye area.

russiensis Mjatl., Vaginulina lanceolata Küb. et Zw., suggesting most likely an Oxfordian or Kimeridgian age. Considering the stratigraphic position of these "red breccias", an Oxfordian age is the more probable.

Over a distance of 2.5 to 3 km west of Pshekha River, limestone breccias are replaced by calcareous-terrigenous flysch represented by bluish-gray shale with beds of gravel and medium-coarse breccias. Present in the shale are the following foraminifera: Trochalina nidiformia (Brück.), Lenticulaina ala Küb. et Zw., L. ex gr. protracta Born., L. attremata Küb. et Zw., Vaginulina lancelata Küb. et Zw., and Polymorphina bilocularis Terq.

Thus, the distribution of facies, typical of the Kimeridgian and Tithonian, had been determined on the whole as early as the Oxfordian.

RELATIONSHIP BETWEEN THE FACIES CHANGES IN UPPER JURASSIC DEPOSITS AND TRANSVERSE FAULTS

Thus far, what has been said shows that the isolation of the eastern and western facies zones prevailed during the entire Late Jurassic, beginning with the Callovian; during all that time, the well defined eastern boundary of the flysch trough occupied about the same position, submeridional along the western margin of the Lagonak zone (Figure 4). The area west of there underwent steady and considerable subsidence, in relation to the Lagonak zone. The Callovian is about ten times thicker here than in the Lagonak zone. In the period of widespread development of Oxfordian, Kimeridgian, and Tithonian limestone facies, sedimentation in the flysch trough lagged behind the subsidence, resulting in a sharp bathymetric step along eastern margin of the trough, with a chain of reef masses along its high side. A train of limestone breccia descended westward from that chain, with the breccia accumulating along the reef slopes, down the eastern escarpment, and at its base.

The nature of this eastern boundary of the flysch trough gives reason to expect a deep fault zone in the folded pre-Callovian basement. Considering the magnitude and the length of displacement, this fault zone may be regarded as a deep fault. The progressive development of this fault, which we have named the Tsitsa, appears to have affected the post-Callovian sedimentary sequence. It is expressed in the present-day structure as a series of faults trending due north and north-northwest (Figure 1).

It appears that in the east, too, the Lagonak transition zone is bound by a submeridional deep fault, although with a smaller displacement. It is now expressed in the numerous faults along the Kurdzhips valley, with some of them showing evidence of recent activity [22]. Areas east of the Kurdzhips fault are characterized by subplatform conditions, in the Late Jurrasic (and later on).

EVIDENCE OF A DEVELOPMENT IN THE TSITSA AND KURDZHIPS FAULTS, CONTEMPORANEOUS WITH POST-JURASSIC SEDIMENTATION[3]

The effect of transverse faults in the Lagonak zone is very marked in the distribution of Lower

[3]Lower Cretaceous data in this chapter are after N.P. Luppov [13], V.V. Drushchin, and Yu.K. Burlin (1960); Upper Cretaceous, after B.M. Keller [9] and M.M. Moskvin; Tertiary, after V.A. Grossgeym [8], K.O. Rostovtsev, and V.N. Buryak [19].

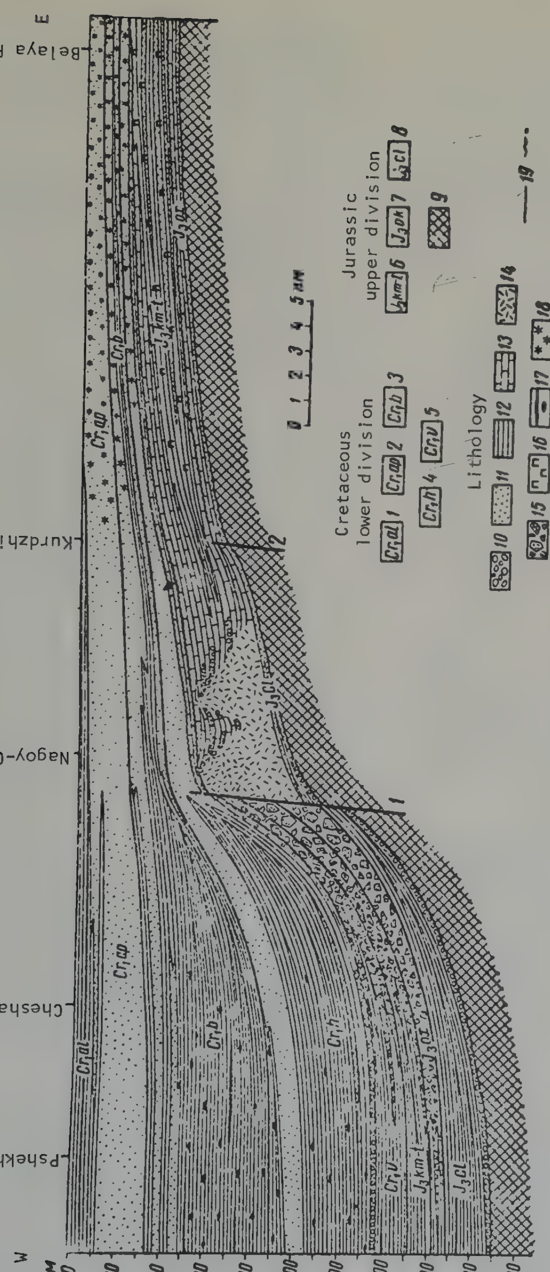

FIGURE 4. Stratigraphic cross section of Upper Jurassic and Lower Cretaceous deposits in the Belaya-Pshekha watershed.

1 - Albian; 2 - Aptian; 3 - Barremian; 4 - Hauterivian; 5 - Valanginian; 6 - Kimeridgian and Tithonian; 7 - Oxfordian; 8 - Callovian; 9 - Underlying rocks; 10 - Conglomerate; 11 - sandstone, siltstone; 12 - shale, marl; 13 - limestone, oncolitic, organic, and oolitic; 14 - bioherm limestone; 15 - limestone breccia, conglomerate breccia; 16 - mottled deposits; 17 - sideritic lentils and concretions; 18 - glauconite; 19 - conformable stratigraphic contacts; 20 - erosional surfaces. Numerals in cross section: 1 - Tsitsa fault; 2 - Kurdzhips fault.

Cretaceous facies and thicknesses. The Lower Cretaceous is missing in the east, within the most uplifted area of the Bolshaya Laba basin. Its upper horizons appear in the basins of Gubs, Fars, and Belaya Rivers, followed by progressively deeper horizons, to the west, represented by littoral facies. Only a small thickening of these deposits has been observed farther on, as far as the Lagonak zone; an abrupt replacement of subplatform facies by flysch takes place west of the Tsitsa fault zone and the total thickness of the Lower Cretaceous is increased by a factor of five.

Valanginian deposits are still similar to the Upper Jurassic in composition and distribution of facies. They are represented by a 50 m thick member of organic and oölitic limestone in the east along the Kurdzhips River; in the west, along the Pshekha, by a flysch section of marl intercalated with clastic limestones, a total thickness of 250 to 300 m. The presence

of Valaginian deposits in the transition zone has not been demonstrated paleontologically; it may be assumed, however, that the corresponding deposits are represented here by upper horizons of the Tsitsa basin reef limestones and by the Chernogor'ye limestone breccia.

Beginning with the Hauterivian, and in connection with a sharp increase in the amount of terrigenous material arriving at the basin, the trough west of the Lagonak zone began to be filled up; that process was completed on the whole in the Barrhemian. Along Belaya and Khokodz Rivers, the Hauterivian and Barrhemian are represented by cross-bedded sandstone and conglomerate, with a total thickness of about 250 m; corresponding to them along the Pshekha is a flysch sequence of shale interbedded with sandstone and siderite beds; the Hauterivian here is as much as 650 m thick, while the Barrhemian attains 1500 m. Thus, the over-all Hauterivian-Barrhemian thickness increases almost ninefold, west of the Tsitsa fault. The contrast between the sections on either side of that fault, in addition to the lithology and thickness, is in the finer details. As noted by I. A. Konyukhov, sediments in the uplifted eastern block are more glauconitic, while an abundance of siderite lenses and concretions has been observed in the downthrown western block. In addition, there is a difference in the micro- and macrofauna.

In the Aptian and Albian, sedimentary conditions became somewhat more equalized within these areas. Corresponding to these stages in the east (along the Khokodz River) are quartzose glauconitic siltstone and argillaceous sandstone, about 300 m thick, which change to about 550 m of shale with siltstone and sandstone beds, along the Pshekha River.

In the Upper Cretaceous, the two facial zones are again more pronounced. In the east, the Upper Cretaceous is represented by a 55-60 m thick limestone bed with chert, marl, and glauconitic sandstone, corresponding to all stages, from Cenomanian through Maastrichtian. From its exposures along Malaya Laba, Khodz, and Kurdzhips Rivers, this bed is traceable westward, as far as Mt. Samurskaya whose summit it makes up. To the west (beyond the Tsitsa fault), the Upper Cretaceous (Campanian-Maastrichtian) is represented by a thick (about 630 m) flysch section of marl, limestone, and siltstone (the Kotkh formation).

The fault movement of the Lagonak zone, contemporaneous with sedimentation, continued in the Paleogene, including the Middle Eocene. The total Paleocene- Middle Eocene thickness increases more than tenfold west of that zone: from 125 to 1500 m. In that direction, marl, shale, and glauconitic sandstone (formations Elburgan, Goryachiy Flyuch, Abazinsk, and the base of foraminiferal beds) are replaced by terrigenous and calcareous-terrigenous flysch (Tsitsa, Goryachiy Klyuch, Il'sk, Zybzinsk, Kaluga, and Khaduzhensk formations), with the stratigraphic range of the section growing larger.

In the Late Eocene, during the deposition of the Kuma and Belaya Glina formations, differences between the facies zones became somewhat obliterated. Shale, marl, and limestone were deposited at that time over the entire area, with only the glauconitic sandstone restricted to the eastern zone. The Upper Eocene section grows thicker from east to west, from 50 to 150 m.

Beginning with the Oligocene, the deposition continued only north of this area, in the west Kuban and east Kuban troughs, with the thickness of the facies still affected by the Lagonak transverse escarpment (its northern projection). Maykop deposits change little in thickness from east to west: from 400 m to 1000 m, with sands, petroliferous in the Apsheronsk - Goryachiy Klyuch area, appearing in the Lower Maykopian (Khadum formation). No appreciable changes in the thickness of Chokrakian and Karaganian deposits have been observed on either side of the Lagonsk zone. However, movements along the Tsitsa and Kurdzhips faults were revived in the Sarmatian; as a result, about 800 m of sediments were deposited west of there, in post-Karaganian time, with only some 100 m deposited in the east. We have found evidence of recent (Pliocene or Anthropogene) movements along the Kurdzhips faults, in a mountainous part of the area (along the Kurdzhips headwaters), with an apparent displacement of over 200 m [22]. Judging from the distribution of the epicenters of modern earthquakes [5], the Lagonak zone is still marked by somewhat higher seismic activity.

Thus, shifts in the Tsitsa and Kurdzhip fault zones continued in post-Jurassic time and into the present. At all times, the area west of these faults has been more or less consistently depressed with relation to the high block in the east. As illustrated in the diagram (Figure 5), this subsidence did not proceed at the same rate, being more rapid in the Callovian, Barrhemian, and Paleocene - Middle Eocene. The total relative subsidence of the western block, since the Callovian, has been about 6 km.

As shown in a previous work [21], this fault zone persists in the south slope area of the Main Range, with the eastern ends of Amuko and Akhtsu Ranges located on the projection of the Tsitsa fault. In the Amuko area, Toarcian-Aalenian beds plunge rapidly under the transgressive Tithonian-Valanginian flysch; in the Akhtsu area, Malm reef limestones plunge under the equally transgressive Middle Eocene (Figures 1). Younger deposits are exposed on an extension of the Amuko uplift, in the deep

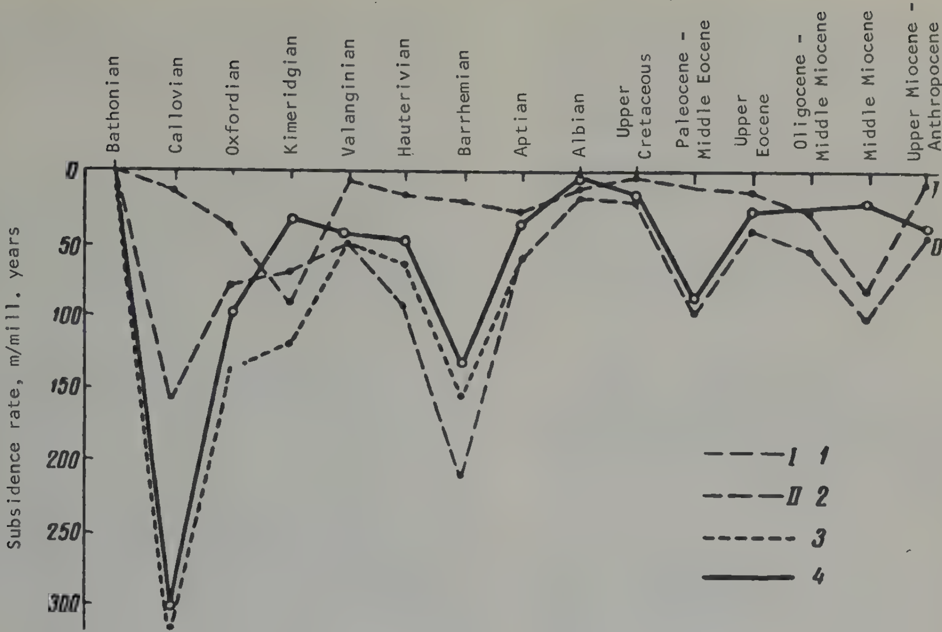

FIGURE 5. Diagram of changes in the subsidence rate for the western zone (west of the Tsitsa and Kurdzhips faults).

1 - Sedimentation rate in the eastern zone; 2 - sedimentation rate in the western zone; 3 - subsidence rate of the western zone; 4 - subsidence rate of the western zone relative to that of the eastern zone.

valley of Shakha River, immediately to the northwest. Curiously enough, in the Dagomys uplift, en echelon to the Akhtsu, the Malm is represented by non-reef facies, while limestone breccia appears in the Tithonian. It is possible that here, along a cross fault, reef limestones are replaced by breccia, as is the case in the north. Another alternative is that the "Dagomys" facies of the Tithonian represent deposits on the north slopes of the reef masses.

Farther to the south, a continuation of the Tsitsa fault has not been observed within the Sochi-Adler trough, although its eastern slope lies on a projection of the Kurdzhips fault. Differential movements along that side were most conspicuous in the Oligocene when the Gagarin massif was intensively uplifted while the Adler trough was just as intensively depressed. It was then that masses of Upper Jurassic and Cretaceous limestone debris debouched from the mass, to be buried in Oligocene "inclusion-bearing horizons" [11].

Earlier movements of the same nature are suggested by the east-west changes in facies, observed within the Gagarin mass itself. Stratified Neocomian limestones change eastward to rudistid bioherms (according to M. S. Eristavi, V. B. Olenin, and B. A. Sokolov), while the Oxfordian-Tithonian reef limestones are replaced, in the vicinity of Bzyba River, by a motley lagunal sequence (after N. S. Bendukidze) where the facies changes are quite similar to those described for the Lagonak Range.

North of the Abkhaz and Adler zones, definite changes have been observed in the same probable extension of the Kurdzhips fault. The Chvezhipsin tectonic zone (identified by M. V. Muratov, [15]), with its transitions from flysch to non-flysch facies, or more precisely an interweaving of both, accompanied by strong overthrust and by recumbent to overturned folds, rapidly narrows down, east of Mzmyta, and practically disappears, being transformed into a synclinal trough within the Abkhaz zone. These changes are accelerated by an oblique fault along Mzmyta, noted by V. I. Slavin and S. L. Byzova (Caucasian Expedition of Moscow University). A large frontal overthrust, the Vorontsov nappe, terminates in the same locality. It was identified in their time by B. M. Keller and V. V. Menner.

As noted in another work [21], the Tsitsa and Kurdzhips faults should be regarded as elements of a major transverse structure which bounds the Adygey (Maykop) transverse uplift and Central Caucasus as a whole on the west. An extension of this structure is found in the Pre-Caucasus [17, 20, 21], and in the Black Sea, at the opposite end. In significance, it is comparable to the fault zone marked by N. S.

Shatskiy east of the Mineralovodsk and Stavtopol uplifts, from studies by G. P. Leonov, M. V. Muratov, and others. All these are first order faults on the scale of the Greater Caucasian geosynclinal system. In addition, a number of second order transverse faults and flexures have been identified by the authors of this article and by others (N. A. Syagayev, S. L. Afanas'yev, A. N. Shardanov), for the Western Caucasus, at Tuapse, Dzhubga, Kabardinke, and Anapa meridians. Along these steps, the Caucasus gradually plunges toward the straits of Kerch.

CONCLUSIONS

It should be stressed that features of the structure and facies changes described here for the transition zone between the central and western Caucasus also have a more general significance.

1. Transverse faults are common to all geosynclinal folded structures which they divide into segments different in geologic history and consequently in facies, thickness, unconformities, type of structure and intensity of folding, type and importance of faulting, etc. Such faults are particularly characteristic of the Alpine zone of Europe and Western Asia. In addition to separating the central Caucasus from the eastern and western, they separate the Caucasus as a whole from the Crimea; the eastern Crimea from the western; the eastern and western Carpathians; the Carpathians from the Alps; and the western and eastern Alps [25].

2. Their acticity changes with time, the movement along them alternating with that along the principal longitudinal faults, and often coinciding with the principal epochs of folding.

3. Relationship between the Upper Jurassic barrier reef and the fault zone is quite regular. This is corroborated first of all in the Upper Jurassic in the Caucasus, Crimea, Carpathians, and Balkans. Upper Jurassic reefs in the southern fringe of the Georgian flysch trough [7] and at its boundaries in Azerbaydzhan, are associated with longitudinal faults; the Crimean reefs of the same age are located in a transverse fault zone separating the eastern part of the Mountain Crimea from its central part [1]. Lower Permian reefs of the Ural front region [4] and Texas [24], as well as Devonian and Silurian reefs on the western slope of the Southern Urals [10] and Neogene beehive-shaped reefs of the Dnestr region [12] are all located in zones of faults and flexures.

4. Just as regular is the relationship between barrier reefs and flysch. Upper Jurassic and Lower Cretaceous flysch in the Alpine zone of Europe, in the Atlas, Apennines, dinarids, hellenids, Balkans, Crimea, and Caucasus, are connected by facies transitions with reef limestones; in all instances, flysch troughs are bound by faults or flexures, with bioherms on the upthrown sides and with flysch on the downthrown sides. Erosion of these reef masses is one of the sources of clastic material for the flysch troughs.

5. Relationship in the thickness and nature of sediments between zones of reefs and flysch troughs definitely suggests bathyal depths of deposition of flysch bodies, as well as uncompensated subsidence at the beginning of such deposition.

6. The fact that flysch troughs are bound by faults explains the periodic surging of turbidity currents along their slopes and the spreading of coarse clastic material over the bottom. These turbidity currents were caused by shifts along the faults; i. e., they were closely associated with the general oscillatory rhythm of the crust. This concept satisfies the two competing hypotheses on the origin of flysch: the oscillation hypothesis [6] and the turbidity currents hypothesis [23]; it accomplishes that by attributing a special tectonic regimen to flysch troughs.

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ORIGIN AND STRUCTURE OF SWELLS IN THE RUSSIAN PLATFORM

by

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The formation of anteclises, swells, and domes in the Russian platform has been controlled by differential and noncontemporaneous downwarping of individual elements, the components of these forms.

* * * * *

1. PRELIMINARY OBSERVATIONS

The structure of domes has been widely discussed, inasmuch as these forms are associated in the Russian platform with oil and gas fields. Deep drilling in various structures has provided many interesting data on this subject; yet there is no unanimity of opinion on the structure and the genesis of domes and related forms in the sedimentary platform mantle.

Prior to the nineteen forties, most geologists believed that deformations in the eastern part of the Russian platform were related to tangential forces operating from the direction of the Urals [17]. Subsequently, that view was criticized by N. S. Shatskiy [14] who associated these deformations with faults in the Precambrian basement of the platform.

The works of P. Ye. Offman [9] in the Volga region have brought to light many characteristic features of platform deformations. He believed them to be large box- and step-like forms bounded by flexures. Domes which may constitute oil and gas reservoirs are associated with the uplifted limbs of these flexures.

New ideas have gained popularity, in recent years; among them are those attributing prime importance to oscillatory movements as a causative factor in the origin of platform structures. These concepts are concisely expressed by L. N. Rozanov, with reference to specific features in the Second Baku field: "Elongated swells developed over ancient troughs, as the result of a subsequent inversion of the latter, in Carboniferous time. A substantially similar inversion has been recognized for all structures of this type drilled through; many of them existed in the Devonian as local troughs, as witness changes in thickness and lithofacies composition of sediments" ([10], p. 33).

That conclusion has been substantiated by a study of domes complicating the Tatar arch. Thus, in considering the distribution of thicknesses for Devonian and Carboniferous sediments within the Golyushurminsk, Varzi-Yatchinsk, Shugorovka, Baytugan, and other domes, that author points out that the Devonian deposits thicken toward the tops of the domes. That led him to the logical conclusion of the presence of troughs on the sites of present domes. The situation is reversed for Carboniferous deposits which are thinner at the crests of the domes than in the limbs. The conclusion is that a carboniferous dome existed at the site of the Devonian trough. This phenomenon of a trough being transformed to a swell is regarded by L. N. Rozanov as an inversion having originated in oscillatory movements.

A number of other authors are of the opinion that the origin of swells cannot always be ascribed to oscillatory movements. For instance, G. A. Brazhnikov believes that domal uplifts in the southern part of the Don-Medveditsa swell "were formed without participation of differential movements in basement blocks" ([1], p. 23). That author explains the formation of domal uplifts by means of a complex scheme which we present in Figure 1.

D. S. Khalturin [13] associates local uplifts and troughs with minor block shifts in the basement. He states, however, that upward movements were paramount in the Russian platform and that "the formation of zones of deformation and of local structures is undoubtedly connected with processes of subsidence and downwarping in the platform. In the course of subsidence,

[1] O stroyenii i obrazovanii kupolov russkoy platformy.

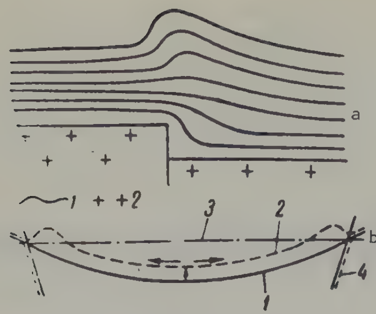

FIGURE 1. Diagram of the formation of a local uplift, after G.A. Brazhnikov.

a - a "rootless structure" of the Stalingrad type: 1 - phantom marker horizons; 2 - recrystalline basement blocks; b - formation of Stalingrad-type uplifts to the the constricting surface: 1 - the rising strata; 2 - the same strata reaching the constricting surface; 3 - the constricting surface; 4 - bracings at ends of the flexing strata.

the sediments were warped, which led to the formation of structures" (p. 157).

The purpose of this article is to consider the structure and origin of domal uplifts and swells in the Russian platform, from data on the occurrence of sedimentary mantle within anteclises.

2. THE CONDITIONS OF OCCURRENCE OF SEDIMENTARY MANTLE WITHIN ANTECLISES

The principal tectonic structures in the Russian platform are anteclises and syneclises formed by Riphean, Paleozoic, and Mesozoic deposits. Within those structures, these deposits occur in different ways at different depths, depending on changes in thickness and on the unconformable position of individual stratigraphic complexes. It should be stressed that the completeness and thickness of Paleozoic sections differ substantially not only on the opposite limbs of the anteclises but on the same limb, as well.

The data on hand show that the local unconformable positions of beds and the differences in their thickness are caused by a differential and noncontemporaneous development and transformation of various parts of anteclises, syneclises, swells, and smaller tectonic forms. This diversity is peculiar to structures in the Russian platform, which we shall attempt to demonstrate in specific examples.

In the northern limb of the Voronezh anteclise, Precambrian formations are overlain directly by Devonian deposits, plunging north of the anteclise to participate together with the overlying Carboniferous in the structure of the Moscow syneclise.

In the southern limb of the Voronezh anteclise, Precambrian beds are overlain directly by Carboniferous deposits; the latter, plunging south, participate in the structure of the Dnepr-Donets trough. These data indicate that the downwarping of the northern limb began in the Devonian; and of the southern limb in the Carboniferous. Thus, it appears that the Voronezh anteclise was formed by noncontemporaneous subsidence of its segments. A similar situation prevailed in the Mesozoic.

Thus, in the northern limb, Devonian deposits, dipping gently to the north, are overlain unconformably by Mesozoic rocks dipping even more gently to the south. The northerly dip of Paleozoic rocks originated in their deposition in the subsiding Moscow syneclise.

In the Mesozoic, on the other hand, the subsidence of the Dnepr-Donets trough was more intensive than in the Moscow syneclise, so that Mesozoic deposits are dipping south. The progressive southerly subsidence of Mesozoic beds brought about southerly dips in the underlying Devonian and Carboniferous deposits. The flexing in Mesozoic beds was not strong enough to disturb the homoclinal position of Paleozoic deposits [3-4]; it did not lead to an appreciable modification of their structure, except for flattening their dip somewhat [8].

A similar situation has been observed for the Tokmovo and Tatar arches. The southwestern slope of the Tokmovo massif, coinciding with the Pachelma trough, was most intensively developed in the Riphean, when Precambrian formations were widely developed on its eastern and western limbs. The eastern limb of the Tokmovo massif began to be formed in Late Devonian and especially in Carboniferous time, when the Melekess trough was formed.

The conditions of development for the eastern slope of the Tokmovo mass are well illustrated in N. G. Suvorov's cross sections [11] reproduced here as Figure 2. A vast uplift occupied its site in the Okhotnichya station area, in the Middle and Late Devonian. The western limb of the Tokmovo uplift was located in the Tokmovo village area, where its present crest is located. Famennian deposits cover the entire area between Tokmovo and Melekess. In the Famennian, a gentle subsidence was initiated above the uplift, in the Okhotnichya station area, with Upper Devonian beds on its western and eastern limbs dipping east and west, respectively. The position of the Precambrian basement surface in the Tokmovo-Melekess area did not coincide with these dips

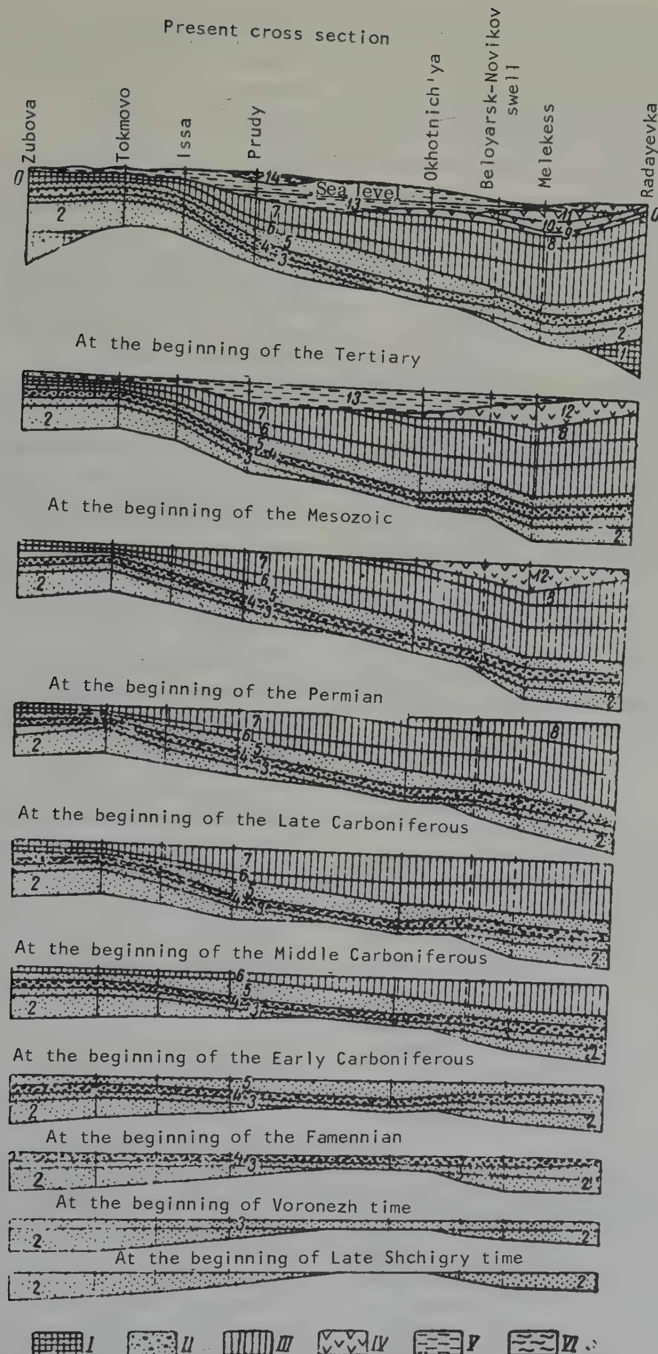

FIGURE 2. Cross sections, Zubova Polyana - Radayevka (after P.G. Suvorov).

1 - Lower Paleozoic; 2 - Givetian stage and the Lower Shchigry Frasnian horizon; 3 - Upper Shchigry, Rudkino, and Semiluki Frasnian horizons; 4 - Voronezh, Yevlanovka, and Livenka Frasnian horizons; 5 - Famennian stage; 6 - Lower Carboniferous; 7 - Middle Carboniferous; 8 - Upper Carboniferous; 9 - Lower Permian (Sakmarian and Artinskian deposits); 10 - Upper Permian (Kazanian and Ufa deposits); 11 - Upper Permian (Tatarian deposits); 12 - Lower and Upper Permian; 13 - Mesozoic; 14 - Cenozoics. Deposits: I - Lower Paleozoic; II - Devonian; III - Carboniferous; IV - Permian; V - Mesozoic; VI - Cenozoic.

in Upper Devonian deposits. In Carboniferous time, a small subsidence was going on nearer to the present Melekess trough. In the course of Carboniferous sedimentation, a homocline of Devonian and Carboniferous deposits was formed, dipping to the east. Because of that, the Carboniferous section within the Tokmovo arch is much shorter.

A trough filled with Permian deposits was formed in that homocline, so that Devonian and Carboniferous dips in its western limb are steepened; for the same reason, they are flattened in the eastern limb (Figure 2).

The Ul'yanovsk-Saratov syneclise was formed in eroded Carboniferous and Permian deposits forming a homocline dipping very gently to the east. In the west of the syneclise (Issa - Prudy villages) the direction of dip in Paleozoic and Mesozoic bdes coincided, this steepening the Paleozoic dips. The situation was reversed in the eastern part of the syneclise, because the formation of the eastern limb brought about westerly Mesozoic dips where the earlier Paleozoic dips had been to the east. Carboniferous and Permian beds in the eastern limb of the Ul'yanovsk-Saratov syneclise rest with a flatter dip than that of Devonian beds, because the Devonian beds were steeper, prior to the formation of the syneclise, than the overlying beds.

Mesozoic beds in the Ul'yanovsk-Saratov syneclise dip toward its center (Figure 2), while Paleozoic deposits in it, between Tokmovo and Melekess, form a homocline dipping to the east. It follows that the relationship between the Mesozoic and the underlying Paleozoic rocks is different in the western and eastern limbs of the syneclise. In the west, the two systems are conformable, dipping in the same direction; in the east their dips are opposite. Such relationships between Mesozoic and Paleozoic beds is quite characteristic, originating as they do in a differential and, what is more important, noncontemporaneous warping of individual segments of a structure.

The magnitude of warping is quite important. If the Mesozoic warping of the Ul'yanovsk-Saratov syneclise had been greater than it was, the dip of Carboniferous and Permian beds in its eastern limb would have been flattened until they became horizontal, and finally bent in the opposite direction (from easterly to westerly dips). The same situation could have come about for Devonian deposits and for the basement surface. They, too, could have their dips modified; however, their reversed or westerly dip would have been flatter than that of Carboniferous and Permian beds, because dips of the Devonian rocks and the basement surface, at the onset of the Mesozoic trough, had been steeper than in the overlying deposits. After a certain subsidence, isolated segments of a homocline can become troughs.

Thus, changes in the position of various sedimentary units in the eastern wing of the Tokmovo arch took place in the course of a differential subsidence and of the formation of Permian and Mesozoic troughs in a gentle homocline.

Similar phenomena took place in the evolution of the Tatar arch. Its southern and eastern limbs were formed in connection with the shaping up of troughs along its corresponding margins, accompanied by a Riphean deposition. During the Devonian, the evolution of the southern limb and the initiation of the western and northwestern limbs occurred. These two slopes were developed at different times. According to A. I. Kleshchev [4], there was no deposition in the Early and Middle Devonian, in the northwest of the Tatar arch where the Precambrian basement was exposed; sedimentation occurred in the southern part of the arch. At the onset of the Late Devonian, the Precambrian basement began to subside and was covered by Devonian deposits, different in different parts of the same structure, because of the differential subsidence. Subsequently, these segments of noncontemporaneous sedimentation formed the present Tatar arch. The differential nature of that subsidence is expressed in the differential thickness of sediments and in a step-like structure of its limbs.

Thus, we see that the development of the Voronezh anteclise, the Tokmovo mass, and the Tatar arch was determined by the corresponding troughs. In this connection, N. S. Shatskiy believed the anteclises to be residual structures; that syneclises were the active tectonic forms; and that "in outline, anteclises are subordinate to syneclises and passively occupy the space between the latter" ([16], p. 43).

3. THE CONDITIONS OF OCCURRENCE OF SEDIMENTARY DEPOSITS IN SWELLS

Swells occur in the limbs of syneclises, in their most warped parts. Such arrangement determines differences in the limb structure of the same swell. Obviously, downdip limbs are different from the updip ones.

An example is the Don-Medveditsa swell, in the eastern limb of the Voronezh anteclise and trending parallel to the rim of the Near-Caspian syneclise. The structure of the eastern limb of the Voronezh anteclise is known from data on the depths of Precambrian formations and on changes in the thickness of Paleozoic deposits. In the Uryupinsk area, the basement lies at 400 m; in the Yelan area, 120 km to the east, at 2100 m, an average dip of 14 m per km. It lies at 2858 m, in the Klenovo structure, 40 km farther east, a dip of 18 m per km. Only the Shchigry Upper Devonian deposits have been penetrated at about 3000 m, in the western

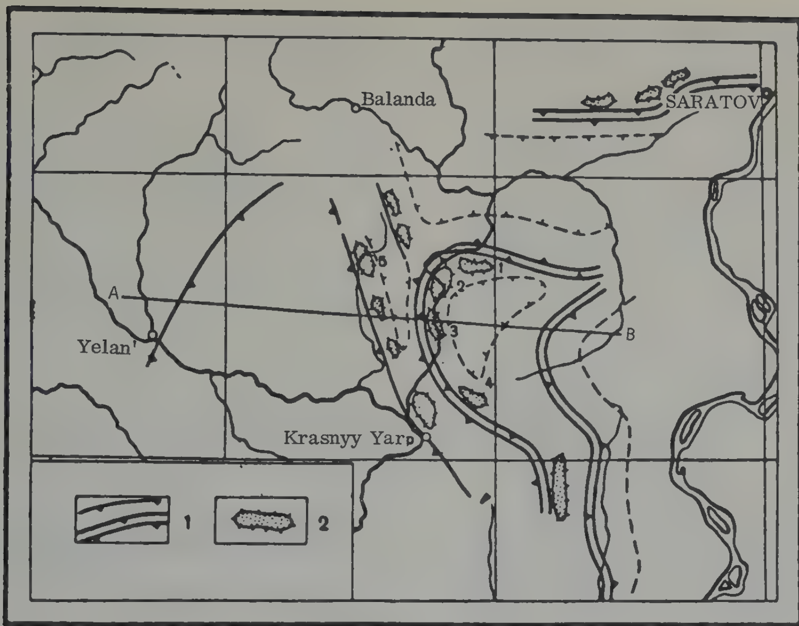

FIGURE 3. Tectonics of the northern part of the Don-Medveditsa swell (after P.Ye. Offman).

1 - flexures; 2 - domal uplifts: 1 - Peskovatskiy; 2 - Bakhmet'yevka; 3 - Zhirnovo; 4 - Linevka; 5 - Klenovka.

imb of the Don-Medvedita swell (Zhirnov lome), 35 km farther east (Figures 3 and 4). As determined by geophysics, the basement here is 4000 to 4500 m deep.

If that computation of the basement depth is approximately correct, the average dip on the basement, here, is as much as 47 m per kilometer. It should be stressed that average dips are of

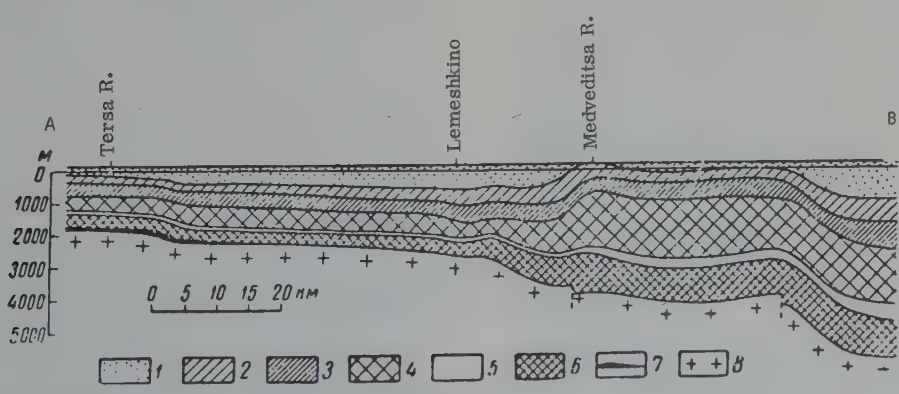

FIGURE 4. Generalized cross section along A - B (across the northern part of the Don-Medveditsa swell). Compiled by A.I. Mushenko from published data.

1 - Mesozoic and Cenozoic deposits; 2 - Middle and Upper Jurassic; 3 - Lower Carboniferous; 4 -

1 - Mesozoic and Cenozoic deposits; 2 - Middle and Upper Jurassic; 3 - Lower Carboniferous; 4 - Upper Devonian; 5 - Upper Devonian Shchigry deposits; 6 - Middle Devonian; 7 - Bavly deposits; 8 - Precambrian formations.

little value in determining the basement structure. It can only be inferred that the dip steepens eastward and that the basement plunges at an uneven rate. The average dip does not reflect the true picture. For example, a flexure with an easterly dip has been inferred from the occurrence of Mesozoic Carboniferous beds east of Yelan'. This flexure appears to be reflected as an escarpment in the basement surface. In its vicinity the basement dips at an angle steeper than average; farther eastward, however, they are flatter than average.

Paleozoic deposits thicken eastward, with the increase in the basement dip. Along with the gradual thickening, they display abrupt local thickenings over short distances. Thus, the Semiluki Upper Devonian beds are 60 m thick in the Yelan' area; 72 m in the Klenovka area; and thicken abruptly to 500 or 550 m in the steep western limb of the Don-Medveditsa swell. That easterly increase in thickness is determined by an abrupt subsidence. The overlying sediments in that area also thicken substantially, although not as rapidly as the Semiluki beds. Thus, the presence of a basement escarpment along the present western limb of the Don-Medvedita swell is inferred from the abrupt thickness increase in Paleozoic deposits. A thickening of sediments of that age has also been observed farther east of the Zhirnovo dome, as inferred from borehole sections in the Linevka dome to the east. It appears then that a Paleozoic homocline, differentially plunging to the east, was being formed in Paleozoic time, on the site of the present swell.

In the Mesozoic and Tertiary, the Tersa trough was developed in the Tersa River basin, on the background of this general easterly plunge toward the Near-Caspian syneclise. Its east flank was associated with an ancient escarpment running along the western limb of the Don-Medveditsa swell. Mesozoic deposits form a flexure over it, dipping to the west, with dips up to 20°. Consequently, Mesozoic dips in the flexture are opposite to those of the Precambrian basement. These relationships in the occurrence of beds are illustrated in a diagrammatic cross section (Figure 4), also in G. A. Brazhnikov's sketch (Figure 1a).

This flexure, along with the accompanying domal uplifts (Zhirnovo, Bakhmet'yevka, etc.), constitutes the western limb of the Don-Medveditsa swell; they also represent the eastern slope of the Tersa trough.

In the Tersa trough, the base of the Mesozoic lies at 540 m below sea level. It is 100 m above sea level in the uplifted part of the western flank of the Don-Medveditsa swell. Consequently, the subsidence of Paleozoic rocks within the Tersa trough is as much as 640 m. Judging from differences in the structure of its eastern flank, the subsidence was differential.

In the north, in the vicinity of the steep western limb of the Don-Medveditsa swell, the total thickness of the Cretaceous reaches 300 m. To the south, in the Korobkovo uplift area, the slope of the Tersa trough is marked by flat northwesterly Mesozoic dips of 5 to 10 per kilometer. In that area, Cretaceous deposits are not over 200 m thick. They are 130 m thick along the western limb of the Tersa trough where the Jurassic has been eroded to a considerable extent. It appears then that the most warped part of the Tersa trough is located along the steep western limb of the Don-Medveditsa swell.

These data on the thickness and occurrence of Paleozoic and Mesozoic rocks show that an appreciable development of that limb took place mostly in the Mesozoic and Tertiary, in connection with the formation of the Tersa trough in a gentle homocline dipping west, which determined the change in Paleozoic dips in a westerly direction. The degree of that change was different for different places on the eastern limb of the Tersa trough.

Thus, the course of transformation of the Don-Medveditsa swell, or more precisely of the emergence of its present form, has been fairly definitely reconstructed. Prior to the Mesozoic, the eastern limb of the Voronezh anteclise, made up of Devonian and Carboniferous rocks, presented a gentle homocline, dipping east and complicated in a number of places by escarpments of various heights.

In the Mesozoic, this homocline underwent a transformation continuing into the Cenozoic. Its transformation was rather simple, being reduced to a gentle local subsidence leading to the formation of the Tersa trough, with Mesozoic rocks unconformable over the downwarped segment of the homocline.

The formation of the eastern limb of the Tersa trough was at the same time that of the western limb of the Don-Medveditsa swell. The present structure of the swell is somewhat different along the strike. Thus its dip is steeper in Zhirnoye area than near Korobkovo, to the south. These differences probably are due to a different structure of the Paleozoic homocline in those areas as well as to a greater subsidence of the Tersa trough in the north.

It has been pointed out that lower beds of the Upper Devonian dip east in the western limb of the Don-Medveditsa swell, while the overlying Devonian and Carboniferous beds dip west, as do the Mesozoic beds. That interesting phenomenon has engaged the attention of many geologists and has elicited a number of explanations. We believe that the older (Devonian) beds in the east limb of the Voronezh anteclise dipped more steeply toward the Near-Caspian trough that did the overlying Paleozoic deposits. Accordingly,

ıey were only partially flattened by the down-arping of the Tersa trough. On the other hand, ıe flatter easterly dip of the overlying beds as completely reversed.

Judging from incomplete data on the Korob-ovo uplift to the south, the westerly reversal the dip affected only the upper part of the arboniferous section, while the dip of the nderlying horizons was only flattened.

The eastern limb of the Don-Medveditsa well continued its Paleozoic development in the lesozoic and Tertiary, thus maintaining the riginal direction of its dip. It follows that the eologic development in its eastern and western mbs took different courses from the Mesozoic n, hence the difference in the occurrence of ratigraphic complexes at different depths.

4. THE OCCURRENCE OF SEDIMENTARY DEPOSITS WITHIN DOMAL UPLIFTS

Typical structural forms in the Second Baku rea are linear flexures with dome-like uplifts rranged in chains along their uplifted limbs nd separated by small saddles. These domes ave been well explored by drilling, so that ıeir structure at different depths is known. s an example, we shall consider such domal ructures in the Don-Medveditsa swell area nd in the south limb of the Tatar arch. The akhmet'yevka, Zhirnovo, and Nizhnedobrinsk omal uplifts have been identified along the eridian trend of a flexure in the north of the on-Medveditsa swell. They illustrate the oc-urrence of various beds at different depths nd explain the unconformities separating them.

Exposed at the crest of the Zhirnovo dome re Middle Carboniferous deposits overlain by ıe Jurassic. The dimensions of that struc-ıre, as mapped on the Lower Carboniferous, re 9 km along the major axis and 3 km along ıe minor. The trough which separates it from ıe Bakhmet'yevka dome to the north is only 30 ı deep.

According to V. M. Kotel'nikov [3] and thers, the structure of the Carboniferous and ıe underlying Upper Devonian deposits is irtually the same. The difference begins with ıe Shchirgy Upper Devonian beds and down the ection. These deposits, unlike the overlying nes, dip away rather than toward the crest. onsequently, the Shchigry deposits occur at igher elevations, down the steep western limb, ıan those in the crestal part.

For instance, in comparing the elevation of aleozoic deposits which make up the Zhirnovo nd Klenovka domes (the latter is located to the est, within the Tersa trough, Figure 4), we ee that the top of the Vereya horizon in the atter is 550 m lower than in the Zhirnovo dome; the Upper Devonian, 630 m lower; and the Shchigry deposits, 400 m lower. Farther to the west, in central parts of the Tersa trough, the top of the Shchigry deposits rises 600 to 700 m, compared with the Zhirnovo dome area, while the top of the Paleozoic drops approximately 600 m.

Within the Zhirnovo dome, as elsewhere in the western limb of the Don-Medveditsa swell, deposits below the Shchigry have not been penetrated by drilling. Therefore, there are no direct data on the structure of these deposits, here, or of the basement surface. However, a study of the nature of changes in the thickness of Paleozoic deposits suggests that the Upper Devonian and the basement surface have the same occurrence, on the whole, as the Shchigry Upper Devonian beds.

Thus, the occurrence of Mesozoic, Carboniferous, and most of the Devonian deposits within the Zhirnovo and Bakhmet'yevka domes located on the steep western limb of the Don-Medveditsa swell is different from that of the lower interval of the Devonian section and of the basement surface.

As pointed out before, the formation of the superimposed Tersa trough has led to a change in the direction of dip of the Paleozoic deposits. The latter dip into the regional uplift, in the direction of their thinning. In addition, the formation of a flexure in Mesozoic formations above the ancient scarp, has determined a different position of the Precambrian surface and of Carboniferous beds within the western limb of the Zhirnovo and Bakhmet'yevka domes.

Consequently, the different structure of these domes at different depths has been determined by a change in the original dip of Paleozoic rocks along an ancient scarp, in the Mesozoic.

Another example is the Baytugan dome with its distinct difference in the occurrence of Devonian and Carboniferous deposits. It belongs to the Sok-Sheshma deformation system associated with the southern limb of the Tatar arch and consisting of parallel flexures, trending northeast, with southeasterly dips. The Baytugan dome is located on the eastern flexure (Figure 5).

The Ufa deposits are exposed in the crestal part of the Baytugan dome, with the Kazanian and Tatarian developed in its steep eastern limb, while the Kazanian alone is present in the western limb. The structure of that part of it, drawn on the top of Lower Kazanian, is shown in Figure 6. The crestal part of the dome is 20 km long and 3 km wide. The dip of the Permian beds on the steep east-southeastern limb is 25°; it does not exceed 1° on the flat limb. The difference in the elevation of correlative Permian

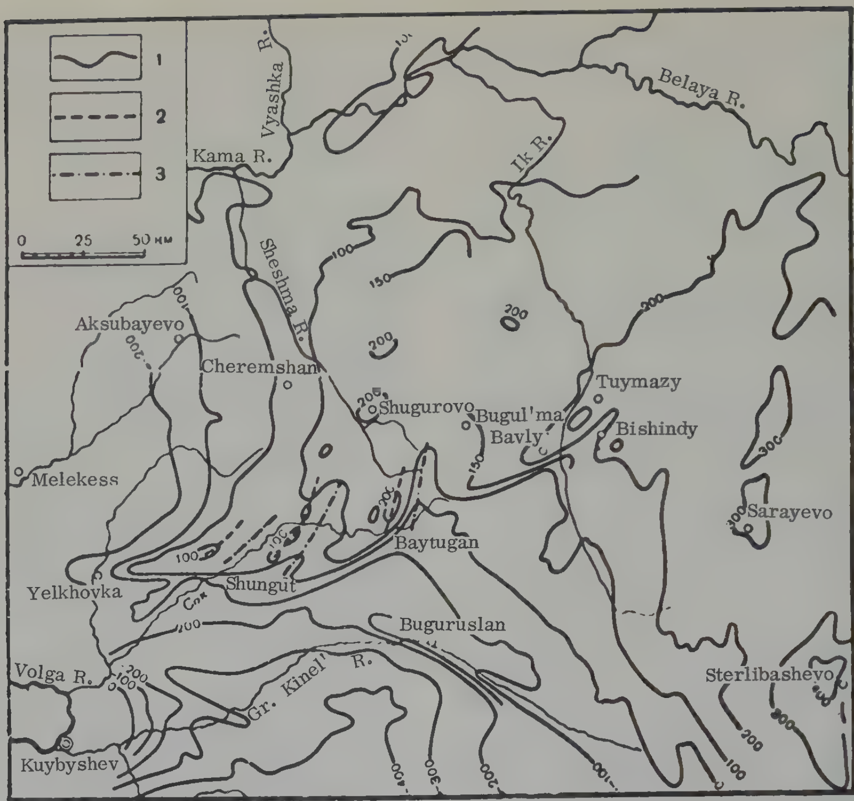

FIGURE 5. Generalized structural map of the top of the Lower Kazanian deposits.

1 - structure contour lines; 2 - axes of local uplifts; 3 - axes of local troughs. After N.N. Forsh.

deposits, in the crest and in the downthrown limb is 50 m; it is 200 m for Carboniferous beds; and 30 m for the Pashiysk Upper Devonian beds.

A better idea of the structure of the Baytugan dome on different stratigraphic levels is gained from maps drawn on the Lower Kazanian substage, Vereya horizon, and a Carboniferous coal-bearing unit (Figure 6, a, b, c). These maps, borrowed from L. N. Rozanov's work [10], reflect a strongly asymmetric domal structure whose dimensions decrease with depth. The position of the crest and the steep limb coincide on the whole on all stratigraphic levels. Maps drawn on the Pashiysk horizon and the crystalline basement differ greatly from the others, in that they show, on the site of the dome, a homocline dipping south and complicated by a structural terrace (Figure 6, e, f).

In the Baytugan dome, the crystalline basement surface plunges unevenly from north to south, from test No. 62 to No. 2. It drops 100 m over a distance of approximately 10 km (from No. 62 to No. 24). In the south (between test holes No. 24 and No. 2), the basement drop is up to 200 m over a distance of 4.5 km. The presence of 200 m of the Bavly section in test hole No. 2, and their absence in No. 24 to the north, along with the considerable subsidence of the basement in that area, suggests that test hole No. 2 is located in the vicinity of a basement scarp which controls the distribution of the Bavly deposits which are widely developed in the Radayevka trough fringing the Tatar arch in the south.

The formation of the Tatar arch was accompanied by a generally southerly thickening of Devonian, Carboniferous, and Permian deposits. A more detailed study has revealed tha this thickening was to the southwest, in the sec ond half of Middle Carboniferous time, as against a southeasterly thickening in the Early Permian. In the Baytugan dome, the total thick ness of Devonian and Carboniferous deposits is less in test hole No. 62 than in No. 24, to the south. According to F. F. Rybakov, the Frasnian is 436 m in test hole No. 24, as against 62 m in No. 248. Differences in the thickness of other intervals are smaller, but are always greater in southern areas.

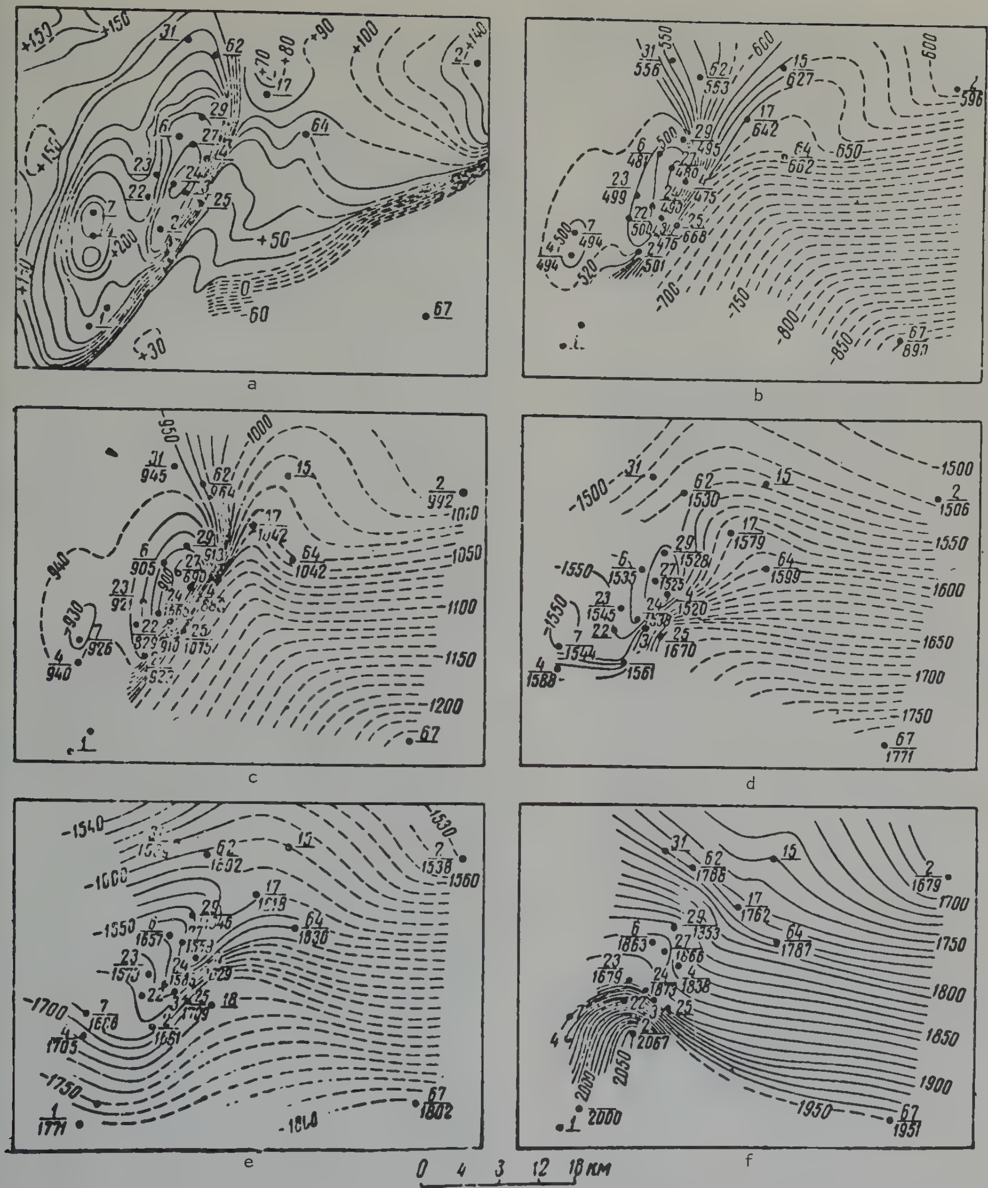

FIGURE 6. Structural maps of the Baytugan area.

Drawn on top of: a - Lower Kazanian substage; b - Vereya horizon; c - Shugurovo beds; d - Pashiysk beds; e - crystalline basement. After L.N. Rozanov.

According to L. N. Rozanov [10], central tests in the Baytugan dome (Nos. 4 and 24) show a thickening of all Devonian units, particularly of the Shugurovo. That author notes that the section is thicker in test holes Nos. 4 and 2 than in No. 17. The thickening of all Devonian deposits by about 150 m is natural, because test holes Nos. 4 and 2 are located south of No. 17. The thickening of these deposits in test hole No. 24, compared with No. 25, is in a westerly direction. These data from a single test are inadequate for assuming the presence of a Devonian trough in the Baytugan dome area, particularly if we consider the possibility of erosion.

L. N. Rozanov has this to say on the origin of the Baytugan dome: "The Carboniferous thickness changes laterally without any apparent regularity; the Tournaisian alone shows a

thinning toward the crest. One gets the impression of a Devonian subsidence, here, being the most intensive in Shugurovo time; Carboniferous movements appear to have been of different signs; while the domal uplift came into being largely in the Permian, at the site of an earlier regional trough" ([10], p. 75).

The data cited above on the thickness of Paleozoic deposits suggest that the Baytugan dome did originate not at the site of a trough but rather on a very flat homocline of Devonian and Carboniferous deposits.

It should be stressed in considering the Baytugan dome structure that Upper Devonian and Carboniferous deposits (over-all thickness of 1450 m) dip to the north, opposite the direction of thickening of those sediments, while the lower interval, Middle Devonian and the base of the Upper Devonian (a total of 300 m), dips to the south, as does the Precambrian basement surface (Figure 6).

Thus, the dip of beds in the lower part of the section corresponds to the direction of regional dip and of thickening, from north to south. That dip was formed during deposition and did not exceed 15'. A continued development of the structure did not change the direction of sedimentation dip. It did, however, lead to a change in the direction of dip in the upper interval. It appears, therefore, that the same process was expressed in different ways in the upper and lower intervals of this section. That is because, following the Carboniferous sedimentation, rocks of the upper interval were deposited with a dip flatter than that of rocks resting directly on the Precambrian basement. A change in the direction of dip of the upper interval came after the Carboniferous deposition, inasmuch as the thickening occurs in a direction opposite to that of the present dip. Such is the longitudinal structure of the Baytugan dome. We now turn to its structure across the trend of the flexure, from test holes No. 24 to No. 25.

The Precambrian basement surface lies at about the same elevation in the crestal and in the downthrown parts of the dome (Figure 24). The base of the Upper Devonian in test hole No. 25 is 50 m lower than in No. 24, with various Carboniferous horizons 170 to 180 m lower, correspondingly. The thickness of the Carboniferous deposits is practically the same, in both test holes. Thus, the distinct flexure in the Carboniferous beds has not been observed in the underlying horizons, or in the basement surface. It follows, then, that beds within the dome become flatter at a certain depth, in both the longitudinal and transverse sections. A comparison of the Baytugan structure along the two cross sections, reveals a great difference in dip of beds. These dips, not over 5 to 15' in the longitudinal section, reach 25° in the flexure zone of the transverse section.

It has been determined that the flexure dips in a number of Second Baku areas steepen with depth. It appears that the flexures correspond to faults in the Precambrian basement, possibly both vertical and inclined. In an inclined fault plane, the loci of flexures are displaced with depth in the direction of dip of the fault plane. In the Baytugan dome, the Precambrian surface lies at the same elevation in test holes Nos. 24 and 25, so that the upward increase in the amount of uplift may be ascribed to the fact that in lower beds the flexure has been displaced to the east. Consequently, a vertical test will drill through different parts of the same flexure, at different stratigraphic levels. In this connection, it cannot be ruled out that test hole No. 25 penetrated the basement on the high rather than the low side. That can be ascertained by drilling another test hole, east of No. 25. It should be stressed that similar relationships in the occurrence of various stratigraphic units along and across the structure have been determined on the whole by the same causes. The presence of a flexure may lead only to supplementary and apparent unconformities between several stratigraphic units (Figure 7).

A study of changes in the thickness of Devonian, Carboniferous, and Permian deposits in the southern limb of the Tatar arch led N. N. Forsh [12] and other students to the conclusion that flexures of the Soksko-Shemskino deformation system had been formed in Permian time. Their formation was accompanied by that of various troughs, northern branches of the main trough fringing the Tatar arch in the north. The Baytugan dome was bounded in the north and east by the Bugulma trough with sides of uneven steepness, the northern slope having quite flat dips. In the south, that trough is bound by the Baytugan flexure.

As pointed out before, prior to the Permian, Carboniferous beds in the south limb of the Tatar arch were dipping to the south. Consequently, the Bugulma trough began as a gentle homocline, with differential subsidence. It is reasonable to suppose that the latter was more intensive in the west, near the flexure, than elsewhere in the trough, because of the maximum plunge of Carboniferous beds, here. There are no data, as yet, on the thickness of Permian deposits immediately east of the Baytugan flexure. We only know that the Ufa deposits are 60 m thick, in the dome, increasing to 90 m in the flexure (test hole No. 24); i. e., by a factor of 1. 5. A result of the Bugulma trough, in an area north of Baytugan, was that along with the Permian beds acquiring a dip into the trough; i. e., to the north, the underlying Carboniferous and Devonian beds were bent in the same direction. Because of that, dips of Carboniferous and Upper Devonian beds changed from a southerly direction to a northerly direction, toward the Bugulma trough.

It should be stressed once more that in order

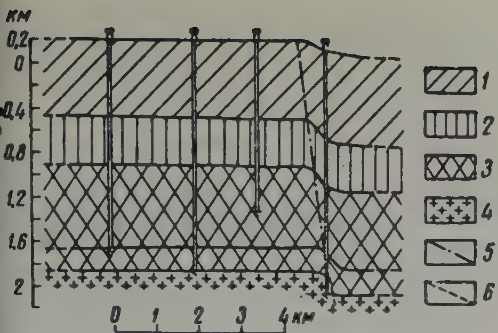

FIGURE 7. Diagrammatic cross section of the Baytugan flexure.

1 - Upper Permian - Middle Carboniferous deposits; 2 - Middle and Lower Carboniferous; 3 - Lower Carboniferous - Devonian; 4 - Precambrian; 5 - assumed flexure; 6 - assumed fault.

to reverse the dip direction from north to south, it was sufficient for the Bugul'ma trough to cause dips in adjacent areas, on the order of 10 to 15' (4 to 5 m per km). It is known from incomplete data that Kazanian deposits in the Bugulma trough occur at an elevation 100 to 150 m lower than in the Baytugan uplift. Only the upper interval of Carboniferous and Upper Devonian beds dips toward the Bugulma trough along its margin, in the northern part of the Baytugan uplift. The lower interval of the Devonian section, as well as the basement surface, maintain their original southerly dip. Now, it is reasonable to support that changes in the direction of dip affected lower as well as upper intervals of the sedimentary section, including the basement surface; i. e., the entire section. However, the upper half of it exhibits appreciable changes, chile dips in the lower half were merely flattened, with their direction maintained. Thus, the Baytugan dome was formed on the southern limb of the Tatar arch, a very gentle homocline. The development of the Bugul'ma trough in it has brought about dips into the trough. There was a possible fault on the west side of the trough, which has resulted in the Baytugan flexure.

SUMMARY

These tectonic forms originated in the course of a differential and, what is more important, noncontemporaneous subsidence of various structural elements. As a result, the tectonic forms were modified, as witness the change of individual homoclinal areas to troughs, with flexures and domes in their flanks. Flexures in upper parts of the section were usually determined by scarps in the homoclinal slope of the lower intervals. Differences in the direction of dip brought about by movements of different periods, have determined differences in the occurrence of the several stratigraphic units, at different depths.

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STRATIGRAPHY OF MESOZOIC CONTINENTAL DEPOSITS IN THE BURYAT A.S.S.R.(WESTERN TRANSBAYKAL REGION)

by

Ch. M. Kolesnikov

This article presents a stratigraphic classification of Mesozoic continental deposits in the western Transbaykal region, based on personal observations by the author and on data obtained by other students.

These data are used in tracing the development of West Transbaykalian troughs in the Mesozoic.

* * * * *

INTRODUCTION

Continental Mesozoic coal measures are fairly well developed in the western Transbaykal region. They are associated with troughs of various sizes, trending northeast to sublatitudinally, parallel to the south and southeastern edges of the Siberian Caledonian platform (Figure 1). These troughs, usually well expressed morphologically, are the valleys of large modern rivers and lakes. Such are the Gusino-Uda, Tugnuy, Kizhinga, and Chikoy-Khilok troughs and a group of troughs in the Vitim plateau.

Within these zones, Mesozoic deposits occur in troughs arranged rosary-like, and separated by outcrops of basement rocks. Within individual troughs, the continental Mesozoic beds form, as a rule, asymmetric synclinal folds.

The geology of these depressions has engaged the attention of such outstanding students of East Siberia as I. D. Cherskiy (1882), V. A. Obruchev (1885, [12]), N. S. Shatskiy (1933), N. A. Florensov (1937, 1954), A. N. Krishtofovich [7], Ye. V. Pavlovskiy (1937, 1948), B. A. Ivanov [3, 4], V. D. Prinada [13], M. S. Nagibina [10, 11], V. N. Vereshchagin (1935), V. P. Plotnikov (1956), S. G. Sarkisyan [15], G. G. Martinson [8, 9], N. F. Karpov (1956, 1957), and others, whose works in this field are well known.

Mesozoic continental deposits in the west Transbaykal region were first mentioned by A. F. Middendorf (1860), P. A. Kropotkin (1873), and I. D. Cherskiy (1882), who believed them to be Tertiary. However, as early as 1910, O. Reis and I. G. Egger established their Upper Jurassic - Lower Cretaceous age [14], from their monographic analysis of a fauna of fishes, freshwater mollusks, and ostracods collected by A. F. Middendorf and A. P. Gerasimov in "paper-thin" slates along the Vitim and Turga Rivers.

More detailed information on the continental Mesozoic of west Transbaykaliya is given by V. A. Obruchev [12] in his major work on the geology of Siberia. That author, who was first to note the regular association of continental Transbaykalian deposits with a system of northeasterly trending troughs, originally believed them to be Tertiary and then, chiefly from the floral identification by A. N. Krishtofovich and V. D. Prinada, Upper Jurassic.

Subsequently, B. A. Ivanov [3] presented the first composite lithologic classification of Mesozoic continental Transbaykalian deposits which he assigned, on the whole, to the Lower Cretaceous. Reading upward, they are as follows:

1. Conglomeratic sandstone formation (conglomeratic breccias, gravels, with subordinate sandstone and shale).

2. Basal arkose (deluvial and alluvial formations having originated in disintegration of granitic rocks).

3. The Turga arenaceous-argillaceous formation (carrying bituminous shale with a typical fauna of fishes, pelecypods, gastropods, crustaceans, and insects).

4. Coal measures (sandstone, siltstone, shale, and coal beds).

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[1] Stratigrafiya mezozoyskikh kontinental'nykh otlozheniy Buryatskoy ASSR (Zapadnoye Zabaykal'ye)

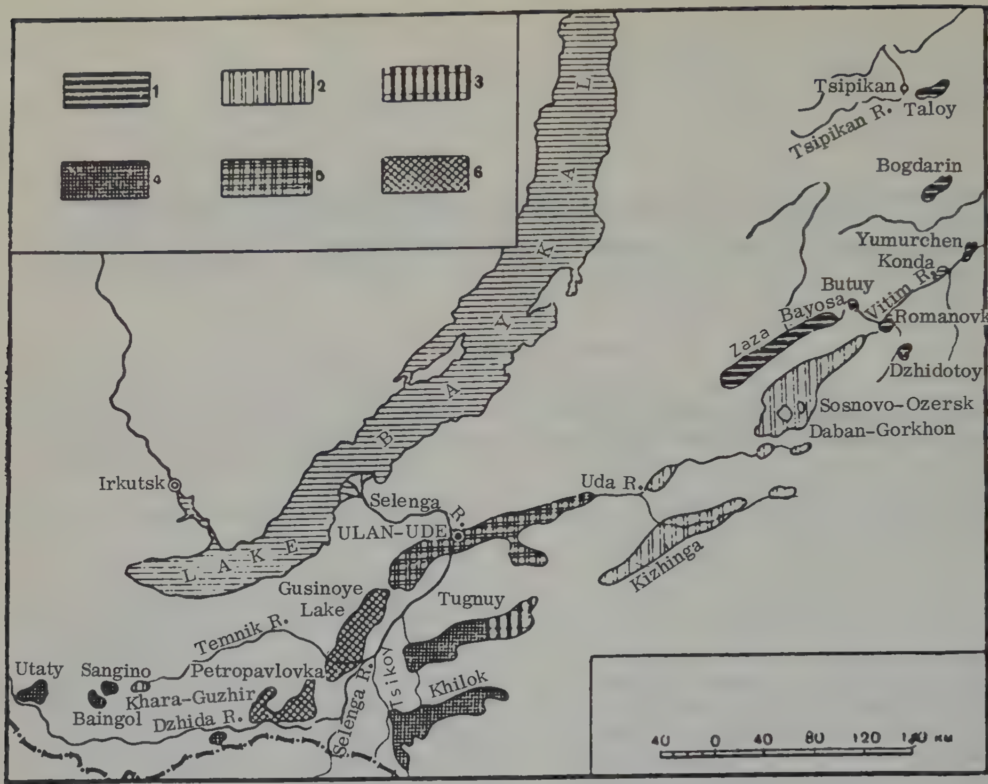

FIGURE 1. Distribution of Mesozoic continental (coal-bearing) deposits in the Buryat A.S.S.R.

1 - Turga-Vitim formation $Cr_1^{(v-h)}$; 2 - same (Vitim and Dabangorkhon subformations) $Cr_1^{(v-ap)}$; 3 - Bukachach formation J_2; 4 - Bukachach and Ulanganga $J_2 + J_3 + Cr_1^{(v)}$; 5 - Ulanganga and Turga-Vitim formations $J_3 + Cr_1^{(v-ap)}$; 6 - Bukachach, Ulanganga, and Turga-Vitim formations $J_2 + J_3 + Cr_1$.

In the following years, V. P. Plotnikov (former Irkutsk Uglegeologiya Trust, 1956) worked out a differentiation of Mesozoic continental deposits from their lithofacies; it was used in exploration field work in Transbaykalia. Reading upward, it is as follows:

1. Extrusive-tuffaceous formation, 1200 to 1500 m thick.

2. Basal conglomerate, 100 to 800 m thick.

3. Arenaceous-argillaceous formation: a) Turga (arenaceous-argillaceous) unit, about 300 m thick; b) sand-gravel unit, 250 to 300 m thick.

4. Coal measures, 200 to 1000 m.

For a long time, the age problem of these deposits was solved differently by different authors [3, 7, 12]. The prevailing opinion was that all Mesozoic deposits of Transbaykalia were of the same age; accordingly, the age of a given bed, as determined by paleontologic findings, irrespective of position in the section, was assigned to the Mesozoic.

Further studies have shown that Mesozoic deposits in different Transbaykalian areas are of different ages. This concept was definitely voiced by M. S. Nagibina [10] on the basis of her detailed lithologic study of Mesozoic sections in various areas of Transbaykaliya. According to her, the Turga formation (continental Mesozoic) is largely Middle to Upper Cretaceous, in the western Transbaykal region, and largely Lower Cretaceous in its eastern part.

The presence of Jurassic and Lower Cretaceous deposits in Transbaykaliya was noted by A. N. Krishtofovich [7] and V. D. Prinada [13], from a faunal study.

Subsequently, G. G. Martinson's work [8, 9] has demonstrated the age difference of fresh-water mollusks collected from continental

Mesozoic beds of various Transbaykalian troughs. He identified four assemblages of freshwater mollusks typical respectively of Middle Jurassic, Upper Jurassic - basal Lower Cretaceous, and middle and lower horizons of the Lower Cretaceous. In 1955, he offered the following general scheme for Transbaykalian continental deposits (reading down):

1) Dain formation, Cr_1^3;

2) Turga-Vitim formation, Cr_1^2;

3) Ulangangin formation, J_3 - Cr_1^1;

3) Bukachach formation, J_2.

In the following years, geologists of the Coal Geology Laboratory, the U. S. S. R. Academy of Sciences, carried on a special geologic study of Mesozoic coal accumulation in Transbaykaliya. On that occasion, this author succeeded in studying continental Mesozoic sections in most of the troughs and collected a large number of fossil freshwater mollusks, phyllopods, gastropods, insects, fishes, and plants.

A study of all data on the stratigraphy of continental Mesozoic in West Transbaykaliya (collected by the author and by others) makes it possible to compile composite stratigraphic sections for the main troughs and to correlate them with a regional stratigraphic scheme based on G. G. Martinson's data.

STRATIGRAPHY

The entire continental Mesozoic section of the Transbaykal region, which we propose to name the Transbaykal coal measures, can be subdivided into three formations and four subformations, on the basis of its fauna (chiefly freshwater mollucks, also phyllopods, ostracods, insects, fishes, and flora), lithofacies, and structure. Reading downward, they are as follows:

1. The Turga-Vitim formation, $Cr_1^{(v-ap)}$, total thickness 860 to 1300 m:

a) Dabangorkhan subformation, 360 to 500 m;

b) Vitim subformation, 500 to 800 m.

2. The Ulanganga formation, J_3 - $Cr_1^{(v)}$, total thickness 400 to 700 m:

a) Bainzurkh subformation, 170 to 320 m;

b) Gusinoozersk subformation, 230 to 380 m.

3. The Bukachach formation, J_3, total thickness 200 to 500 m.

Deposits corresponding to the Dain formation (Cr_1^3), identified in the east Transbaykal region by G. G. Martinson, have not been observed in the west.

The overall thickness of the Transbaykalian coal measures, in the Buryatian A. S. S. R., reaches 2500 m. In individual troughs, certain regional formations and subformations can be subdivided by lithology into local sequences and horizons.

It has been firmly established by now that commercial coal is associated with all three formations. In many troughs, the formations can be differentiated as follows (reading upward): conglomerate, sand and shale, and coal measures, corresponding to lithologic formations of V. P. Plotnikov.

Given below is a stratigraphic description of the Transbaykalian coal measures, by formations, for those troughs in the Buryatian A. S. S. R. where they are best known.

MIDDLE JURASSIC. THE BUKACHACH FORMATION

The Transbaykalian coal measure section begins with Middle Jurassic deposits resting on eroded Lower Mesozoic extrusives, and locally on Paleozoic and Precambrian crystallines.

Continental Middle Jurassic deposits of Transbaykalia are combined into the Bukachach formation, developed largely in the south and southwest of the Buryatian A. S. S. R. as well as in the Tugnuy, Gusinoozersk, and Chikoy-Khilok troughs and in the Dzhida group of troughs.

In all these areas, the Bukachach formation is made up of lacustrine, marsh, and partly alluvial and foothill facies. Resting at its base, as a rule, are medium to coarse (less commonly coarse) conglomerates, changing upward to gravel beds, sandstone, and finally to alternating sandstone, siltstone, and shale with beds of poorly coking coal. Their Middle Jurassic age has been determined from an assemblage of freshwater mollusks of the genus Ferganoconcha, and has been corroborated by paleophytologic data.

As a result of the study of the distribution of Ferganoconchs throughout sections of the Pre-Verkhoyansk marginal trough where continental deposits are interbedded with and reliably dated by marine deposits (G. G. Martinson [9]; N. V. Ivanov and Ch. M. Kolesnikov [4]), their Middle Jurassic age can be regarded as well established. An assemblage of Ferganoconch species, typical of the Bukachach formation, is known also from Upper Jurassic deposits of the Irkutsk, South Yakutian, Chulyma-Yenisey, and Kuznetsk basins, as well as from Fergana, Turgai, and

other regions of Asia, where their age is corroborated by all other paleontologic data.

Associated with the Bukachach formation in West Transbaykalia are the most valuable coal deposits (Tugnuy, Olon-Shibir, Baingol, and Khara-Guzhir).

The maximum thickness of the Bukachach formation in Western Transbaylaliya is 400 to 500 m.

The Tugnuy trough contains the most complete known Bukachach section, developed over a considerable area. The section opens with a thin member of medium to fine conglomerates, gravel beds, and coarse sandstone. They are overlain by a thick sequence of polymictic medium to fine-grained sandstone, siltstone, and shale, with thin beds of gravel, fine conglomerate, and four workable coal beds.

On the basis of lithology, the Bukachach formation can be subdivided into three units corresponding to I. L. Konovalova's local formations (1957): 1) basal sand-conglomerate; 30 to 90 m; b) lower coal measures, up to 350 m thick; and 3) upper barren members, 120 m. The following Middle Jurassic fauna, identified by G. G. Martinson and the author, has been collected from siltstone and shale of various Bukachach units (Figure 2) penetrated by drilling in the central part of the trough [6]: Ferganoconcha estheriaeformis Tsch., F. subcentralis Tsch., F. sibirica Tsch., F. curta Tsch., Sibireconcha lankoviensis Leb., Pseudoestheria sp. In addition, the following plants were identified from the same deposits, by R. Z. Genkina and A. A. Pomerantseva: Goniopteris burejensis (Zal.) Sew., C. angustilobe Brich., C. Maakiana (Heer) Pryn., Cladophlebis denticulata Br., Cl. argutula L. et H., Cl. whitbiensis (Br.) Pryn., Cl. haiburnensis (Br.) Pryn., Raphaelia acutiloba Pryn., Azekanowscia sctacea Heer, Equisetites ferganensis Sew., Elatides munsterii Schenk., Schizolepis grandis Poner., Pityospermum simmetrikum Pomer., etc., also Middle Jurassic, according to them.

Bukachach deposits of the Tugnuy trough rest unconformably on eroded Lower Jurassic melanocratic porphyrite, forming an asymmetic synclinal fold with a steep south limb and a gently dipping north limb. The south slope of the trough is broken by a large fault along which the Bukachach rocks are carbonatized. In addition, the general westerly plunge of the trough is complicated by a number of latitudinally trending synclinal structures separated by anticlinal flexures.

The thickest Bukachach interval (500 m) has been penetrated by drilling in the central part of the trough, south of Sovkhoz Erdem. The formation thins to the east; it wedges out completely in an anticlinal flexure in the Kharauz area, to reappear in the Olon-Shibir synclinal structure [6]. In the higher central and eastern parts of the trough, the Bukachach formation is overlain unconformably by Cenozoic alluvial-deluvial deposits. In the western part of the trough, it is conformably overlain by the Ulanganga formation.

The Bukachach deposits are not as well developed in the Gusinoozersk trough. They are known definitely from the central part of the eastern shore of Gusinoye (Goose) Lake (Figure 3), where their upper interval is exposed in the Tashir ravine, and the lower, near the mouth of it, at the foot of Mt. Bain-Zurkha. In the Gusinoozersk area, the Bukachach formation is unconformable on an eroded surface of Paleozoic crystallines. Its lower part consists of fanglomerate, conglomerte, gravel, and coarse-grained polymictic sandstone. Its upper interval is represented by siltstone alternating with regularly stratified shale, carbonaceous shale, and fine-grained quartz-feldspar sandstone; it carries two commercial coal beds. On the basis of lithology, this formation can be divided into two units: 1) basal conglomerate, up to 160 m thick; and 2) coal-bearing shale and silt, up to 290 m thick. The following Middle Jurassic fauna has been identified from the second unit by G. G. Martinson: Ferganoconcha subcentralis Tsch., F. estheriaeformis Tsch., F. sibirica Tsch., F. anodontoides Tsch., F. curta Tsch., F. minor Mart., F. rotunda Mart., and Bithynis sp.

The following plants have been identified from the same interval, by A. N. Krishtofovich and I. N. Srebrodol'skaya: Coniopteria burejensis (Zal.) Sew., C. obrutshewii (Krass) Pryn., C. saportana (Heer) Krysht., C. hymenophylloides (Br.) Sew., Scleropteris tarbagataica Pryn., Sphenopteris transbaicalica Pryn., Phoenicopsis speciosa Heer, Ginkgo sibirica Heer, Cladophlebis sp., Pithyophyllum nordenskioldii (Heer) Nath., all Middle Jurassic, according to them.

The Bukachach deposits are exposed only on the eastern shore of Lake Gusinoye, in the core of an anticlinal fold. In the north, east, and south, they are conformably overlain by the Ulanga formation.

The Dzhida group of troughs. In the upper courses of the left tributaries of the Dzhida, Bukachach deposits are from the Baingol, Khara-Guzhir, Sangino, and Utaty troughs, although they are fossiliferous only in the first two.

According to data on hand, the area of distribution of Bukachach deposits here is comparatively small. However, it may turn out to be considerably larger if we consider the possible development of coal measures below the widespread mantle of Cenozoic basalt.

FIGURE 2. Correlation of composite stratigraphic sections of Mesozoic continental deposits in central Transbaykalian troughs

I: 1 - pelecypods; 2 - gastropods; 3 - phyllopods; 4 - ostracods; 5 - charophytae; 6 - fishes; 7 - insects; 8 - flora;
II: 1 - coal; 2 - carbonaceous shale; 3 - bituminous "paper-thin" slate; 4 - shale; 5 - siltstone; 6 - alternating shale, siltstone, sandstone; 7 - sandstone; 8 - gravel; 9 - conglomerate; 10 - siderite concretions; 11 - fanglomerate; 12 - alluvium (Q); 13 - extrusives (Cz); 14 - extrusives (Mz); 15 - granite; 16 - metamorphics; 17 - carbonate rocks.

In the Baingol trough, this formation rests unconformably on Cambrian sandstone, crystalline schists of the Dzhida formation, and on other lower Paleozoic and Precambrian rocks; also partly on Lower Jurassic sodium trachyte. The lower interval of the Bukachach formation is made up of medium to fine conglomerate, changing upward, and in part laterally, to light-gray, stratified, polymictic sandstone. This interval may be designated as a sand-conglomerate

unit, up to 100 m thick. The upper part of the formation is represented largely by siltstone and shale, interbedded with fine-grained sandstone and carbonaceous shale and carrying a single workable coal bed. This interval can be designated as the productive unit, about 100 m thick.

The following fossils have been collected by various students from shales in the middle interval (Figure 2) below the coal bed and identified by G. G. Martinson: Ferganoconcha subcentralis Tsch., F. estheriaeformis Tsch., F. andontoides Tsch., F. curta Tsch., F. minor Mart., F. rotunda Mart., F. sp., and Unio sp. Imprints of Sphenopteris cf. ruffordia have been collected from a shale bed above the coal.

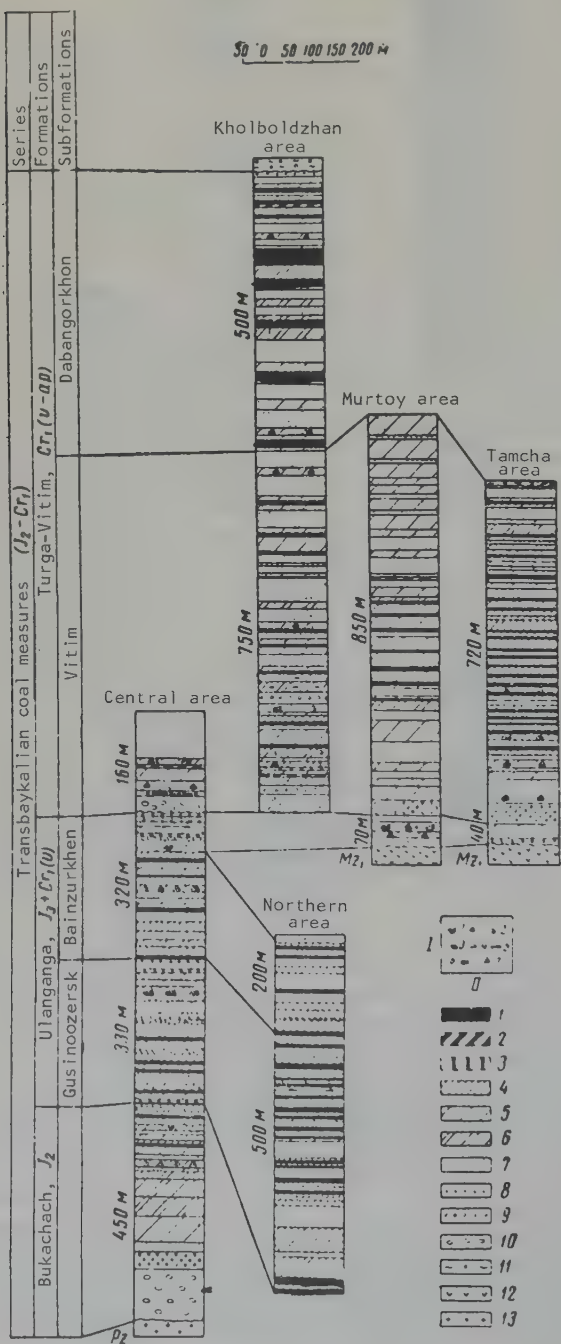

FIGURE 3. Correlation of stratigraphic sections in various areas of the Gusinoozersk trough.

I: 1 - pelecypods; 2 - gastropods; 3 - phyllopods; 4 - ostracods; 5 - fishes; 6 - insects; 7 - flora.

II: 1 - coal; 2 - carbonaceous shale; 3 - bituminous "paper-thin" slates; 4 - shale; 5 - siltstone; 6 - alternating shale, siltstone, sandstone; 7 - sandstone; 8 - conglomerate; 9 - gravel beds; 10 - fanglomerate; 11 - alluvium (Q); 12 - extrusives (Mz); 13 - granite (Pz).

Bukachach deposits of the Baingol trough, together with the conformably overlying Ulanganga formation, form two gentle synclinal folds separated by a latitudinally trending fault which runs along the anticlinal flexure between them.

In the Khara-Guzhir trough, the Bukachach formation, up to 360 m thick, is represented by mixed-grain sandstones and conglomerates, interbedded with siltstone, and carries two thick coal beds. This formation is preserved here only in the north limb of a latitudinally trending synclinal fold whose south limb is in fault contact with Paleozoic granosyenite. Palinologic analysis of carbonaceous siltstone samples taken out of different intervals has given the following results (I. Z. Faddeyeva's identification): Protoconiferus funarius Bolch., Paleoconiferus asacatus Bolch., Cibotium junctum K.-M., Selaginella rotundiformia K.-M., Podozamites sp., Conoferales (rolled up), Osmundaceae, Ginkgoaceae, Cycadales, Benneniatales, and Leitrilites. According to I. Z. Faddeyeva, this spore-pollen assemblage suggests an age not younger than Jurassic most probably Middle Jurassic.

Bukachach deposits are known also from the Chikoy-Khilok trough, where N. A. Florensov has collected the following fossils from an exposure on the right bank of Chikoy River (near the village of Bergovaya), in a siltstone bed of the sandstone interval resting on conglomerate and porphyrite (identification by G. G. Martinson): Ferganoconcha subcentralis Tsch., F. curta Tsch., F. sibirica Tsch., F. estheriaeformis Tsch., F. sp., and Bithynia sp. However, the Bukachach section here is not adequately known.

It is also present in the Borgoy trough, but it is not fossiliferous there.

Beyond the Buryatian A. S. S. R., deposits of the Bukachach formation are known from the Tarbagatay, Bukachach, and Nerchug troughs, where their section is similar to the one described above and is characterized by the same faunal assemblage.

Deposits lithologically similar to the Bukachach and carrying the same fauna and a very similar flora, are known from the East Gobi trough where they have been designated by I. Ye. Turishchev [2] as the Khamarkhubut Middle Jurassic carbonaceous shale formation, 600 to 700 m thick.

UPPER JURASSIC - LOWER CRETACEOUS (VALANGINIAN). THE ULANGANGA FORMATION

These deposits rest either conformably or with a minor hiatus, on the Bukachach formation, and commonly on eroded Paleozoic and lower Mesozoic beds. As compared with the Bukachach formation, this one is more widespread. Its fossiliferous deposits are known from the Gusino-Uda and Tugnuy troughs, and from the Dzhida trough group. In addition, they appear to be present in the Chikoy-Khilok and Bargoy troughs. Associated with the Ulanganga deposits, represented by alluvial, lacustrine, and marsh facies, are large deposits of coal transitional from brown to hard types (such as the Gusinoozersk coal deposits). The total thickness of the Ulanganga formation, in the western Transbaykal region, is 300 to 700 m.

The Gusinoozersk trough has the most complete fossiliferous Ulanganga section, described in 1955 by G. G. Martinson and the author. The most typical Ulanganga sections are known from the central and northern parts of the trough. In addition, its thin intervals represented largely by conglomerate, coarse-grained sandstone, and thin beds of fine-grained sandstone and siltstone, are known from the Murtoy and Tamcha areas on the western shore of Lake Gusinoye, where they rest with an erosional hiatus on Lower Cambrian extrusives (Figure 3).

In the central area, this formation is exposed in Ulan-Ganga, Ara-Ganga, and Tashir ravines. In the northern area, it has been penetrated by shafts and boreholes.

The Ulanganga formation of the Gusinoozersk trough is divided into two regional subformations: Upper Jurassic Gusinoozersk subformation, 330 to 500 m thick; and the Upper Jurassic - Lower Cretaceous Bainzurkh subformation, up to 320 m thick. The Gusinoozersk subformation is represented in its lower part by sandstone interbedded with thin fine-pebble conglomerate changing upward to alternating stratified shale, carbonaceous shale, and coal beds.

This subformation is thickest in the northern area (500 m) where it carries up to 15 commercial coal beds. To the south, the subformation thins down to only about 300 m in the central area, where the number of coal beds is reduced to five.

The following species of freshwater pelecypods have been collected from the approximately correlative Gusinoozersk subformation in the northern and central areas: Lamproscapha lacustris Mart., Unio elongatus Mart., U. grabaui comb. Mart., U. cf. subrostratus Mart., and U. sp.

This assemblage suggests an Upper Jurassic age for the Gusinoozersk subformation. Similar species are typical of Upper Jurassic continental deposits from the Sangary area of the Pre-Verkhoyansk marginal trough, and the Amur-Zeya and Chulyma-Yenisey regions [4].

The Bainzurkh subformation is made up of coarse- to medium-grained sandstone interbedded with siltstone, shale, and carbonaceous shale, with up to four commercial coal beds. Beds of fine- to medium-grained conglomerate appear in the upper interval.

The following freshwater mollusks have been identified from siltstone and fine-grained sandstone in the middle interval, within the central area (Tashir and Aranganga ravines): Lamproscapha tugrigensis Nart., Unio transbaykaliensis Mart., Limnocyrena tani (Grab.), L. sibirica (Ramm.), Lioplax reissi Ramm., Bithynia leachioides Mart.; and the following plants (identified by A. A. Pomerantseva): Coniopteris onychioides Vass., and Onychiopsis elongata Geyl.

Collected from the upper interval, in the central and Murtoy areas, were Lamproscapha murtoica Mart., L. tugrigensis Mart., L. mongolica Mart., Unio aff. grabaui (Dunk.), Limnocyrena sibirica (Ramm.), L. mongolica Mart., L. rammelmejeri Mart., L. shantungensis (Grab.); as well as the following Jurassic plants (identified by A. N. Krishtofovich): Podozamites lanceolatus L. et. H., Pityophyllum sp., and Coniopteris sp.

The assemblage of freshwater mollusks from the Bainzurkh subformation is typical of the uppermost Jurassic and the lowermost Cretaceous in Transbaykalia, Mongoliz, and China.

In the East Gobi trough, deposits with a similar faunal assemblage have been designated as the Tsagantsab formation (Valanginian-Hauterivian), as much as 1300 m thick, represented largely by terrigenous arenaceous-argillaceous rocks rich in tuffaceous material and carrying commercial oil deposits [2].

The Tugnuy trough. Deposits of the Ulanganga formation, represented by mixed-grained sandstone and gravel alternating with fine-grained conglomerates, siltstone, and shale, are known at the present time mostly from the western part of the Tugnuy trough where they rest conformably on the Bukachach formation [6]. These deposits carry sandstone beds with coarse and rough inclusions of the Bukachach formation (siltstone and shale), indicating local erosion during the Ulanganga deposition. In the trough, the Ulanganga formation is overlain almost everywhere by a thick mantle of Cenozoic deposits, except for the Sutay area where its upper beds are exposed. Shale beds in the lower interval of the Ulanganga formation contain remains of phyllopods, scales of ganoid fishes, and some plant remains (Figure 2). According to V. S. Zaspelova, the phyllopods are represented by Brachigrapta wardourensis Nov. and Bairdestheria sp. A. A. Pomerantseva has identified the plant Czekanowskia rigida Heer.

The following fossils have been collected from various upper beds of the Ulanganga formation (in the Sutay outcrop and in well cores): Bithynia leachioides Mart., Pseudoestheria pulcha Nov., Liograpta sp., Pseudoestheria sp., Lycoptera fragilis Huss., and Turgoniscus reissi D. Obrutshev.

The entire fossil assemblage in the Ulanganga formation of the Tugnuy trough is typical of the Upper Jurassic and partly of lower beds of the Lower Cretaceous (Valanginian). Brachygrapta wardourensis Nov., from the lower interval, is typical of middle Upper Jurassic beds, according to V. S. Zaspelova. Another species, Pseudoestheria pulchra Nov., from the upper beds, she believes to occur at the top of the Upper Jurassic. It has been described by N. I. Novozhilov from upper beds of the Dundu-Gobi Upper Jurassic.

D. V. Obruchev has identified a new genus Turgoniscus reissi Obr. among ganoid fishes of the Suray outcrop; he believes it to be somewhat reminiscent of Paleoniscinotus Czekanowskia from the Jurassic of Ust-Baley. According to him, the finding of Paleoniscinidae suggests an age not younger than Jurassic. Freshwater gastropods (Bithynia leachioides Mart.) and fishes (Lycoptera fragilis Huss.), also from upper intervals of this formation, are characteristic of the top of the Upper Jurassic and partly of the base of the Lower Cretaceous in Transbaykalia and Mongolia. Thus, the lower interval of the Ulanganga section in the Tugnuy trough appears to be correlative with the Gusino-ozersk regional subformation; and the upper, with the Bainzurkh.

The Dzhida group of troughs. In the upper course of the Dzhida, fossiliferous deposits of the Ulanganga formation are known from the Sangino and Baingol troughs, where they are conformable on the Bukachach formation and are overlain unconformably by Cenozoic basalt and alluvium.

In the Sangino trough, the Ulanganga formation is made up largely of siltstone and shale interbedded with mixed-grain sandstone and carbonaceous shale. It carries up to 12 workable coal beds (transitional from brown to hard), five of which, according to P. B. Dugarov, are consistent. The most complete Ulanganga section has been penetrated by drilling in the central part of the trough, where it is about 380 m thick. The following freshwater mollusks were identified by G. G. Martinson from the upper part of the Ulanganga formation: Viviparus andreae (Ramm) Mart., V. fusistomus Chi Ping., V. sp., Limnocyrena Shantungensis (Grab.). Plant remains were identified by I. N. Serdobol'skaya as Equisetites cf. naktongensis Tateiwa. According to M. A. Sedova, the spore-pollen assemblage from this interval is quite poor, being represented by a few spores of

Piceae, Pinacease, Podozamites, Cycadales, and Leiotriletes.

The freshwater mollusks listed above are typical of the regional Transbaykalian Bainzurkh subformation (Ulanganga formation). These and similar species are widespread in Upper Jurassic - Lower Cretaceous deposits of Mongolia and China.

In the Baingol trough, the Ulanganga formation is made up largely of shale and siltstone interbedded with thin, fine-grained sandstone. Its most complete section has been penetrated by drilling in the northern part of the trough where it attains a thickness of 300 m. It thins down appreciably to the south. A palinologic study of M. A. Sedova, of shale from its lower interval (from mine dumps) has identified Picea, Pinaceae, Pinus, Taxodiaceae, Brayhyphyllum, Ginkgoales, Podocarpus, Cedrus, Cycadales, Leiotriletes, Mohria, Dicksonia cf. argorescens, and Abies. According to M. A. Sedova, this pollen assemblage is typical of the Upper Jurassic.

In addition, the following Upper Jurassic plants were identified by V. D. Prinada from the middle interval: Ginkgo cf. intergriscula Heer, G. teripora Pryn., Pityophyllum solmsi Sew., Baiera sp., and Sphenopteris sp. Finally, various intervals of this section carry fish remains (skeletal imprints, vertebrae, and scales), assigned to the family Leptolepida, by L. S. Berg (Figure 2).

In the Uda trough, fossiliferous deposits of the Ulanganga formation are exposed in the south slopes of Mt. Lysaya. They are represented by sandstone, siltstone, and shale, with coal layers. According to G. G. Martinson, the Mt. Lysaya siltstones and shales carry Leptesthes elongatus (Ramm), Limnocyrena sibirica (Ramm), L. compacta Mart., Bithynia menguinensis Grab., Valvata suturalis Grab., and other species typical of upper beds of the Upper Jurassic and basal Lower Cretaceous of Mongolia and China.

LOWER CRETACEOUS (VALANGINIAN-APTIAN). THE TURGA-VITIM FORMATION

The Transbaykalian coal measures of the Buryatian A. S. S. S. culminate in the Turga-Vitim formation, the most widespread of all continental Mesozoic formations in the Transbaykal region. Its deposits are known from the Gusinoozersk, Uda, Kizinga, and Zaza troughs, as well as from the numerous troughs in the Vitim plateau (Figure 1). In the southwest, this formation rests erosionally on the Ulanganga formation; in the northeast, it rests unconformably on Paleozoic granites and on Lower Mesozoic extrusives. Its section usually begins with fanglomerate of coarse-pebble conglomerate. They are overlain by a sequence of "paper-thin" bituminous slates and carbonate rocks, alternating with calcareous sandstone and siltstone. Shale and sandstone in this interval often carry siderite concretions. Still higher up, in the middle and upper intervals, brown coal beds appear among siltstones and shales. This formation carries extremely rich assemblages of freshwater mollusks, phyllopods, ostracods, insects, fishes, and plant remains, all typically Lower Cretaceous (Valanginian-Aptian), according to the unanimous opinion of most students.

Many freshwater species from the Turga-Vitim formation are widespread in Lower Cretaceous deposits of Asia. A considerable number of the Turga-Vitim trough Cyrenidae species had been first described by A. Grabau [16] from the Lower Cretaceous of a number of provinces of China. In addition, species of Valvatidae and Planorbidae, very similar to those known from Turga-Vitim deposits, had been described by Dunker (1846), from the Lower Cretaceous of Germany; by Taush (1886), from the Lower Cretaceous of western Hungary; by Mayar (1886), from South France; by Tocer (1956), from Canada; and finally by Stanton (1916) and Yenne (1956), from the Lower Cretaceous of North America.

Associated with the Turga-Vitim formation in West Transbaykaliya are numerous deposits of brown coal (Kholboldzha, Tamcha, Dabangorkhan and Kizhinga). Its total thickness here is approximately 1300 m. It is subdivided into two regional subformations: the Vitim, 500 to 800 m thick; and the Dabangorkhan, 350 to 500 m thick.

The Gusinoozersk trough contains a full section of the Turga-Vitim formation and its two subformations. Deposits of the Vitim subformation make up the upper part of the eastern shore section and most of the western shore section of Lake Gusinoye. In the central part of the western shore, the Vitim beds rest erosionally on the Bainzurkh subformation of the Ulanganga formation, while in the Murtoy and Tamcha areas of the western shore, it rests unconformably on Lower Mesozoic extrusives. Deposits of the Dabangorkhan subformation are known at the present time only from the Kholboldzha area where they make up the upper part of the section (Figure 3).

The Vitim subformation opens with fanglomerates and coarse conglomerates overlain by alternating siltstone, shale, calcareous sandstone, carbonaceous shale, and brown coal. In its lower interval in the central area is a bed of bituminous "paper-thin" shale. The middle and upper intervals, in the Kholboldzha, Murtoy, and Tamcha areas, carry up to 15 workable coal beds. The following lower Cretaceous

species (identified by G. G. Martinson and the author) has been collected from bituminous slate and calcareous sandstone of the lower Vitim interval exposed in Ara-Ganga and Khayan ravines, on the eastern shore of Lake Gusinoye: mollusks Limnocyrena selenginensis, L. altiformis (Grab.), L. wangshihensis (Grab.), L. shantungensis (Grab.), Cyraulus laevis (Ald.) Mart., Probaicalia vitimensis Mart., Valvata turgensis (comb. nov.) Mart.; phyllopods (identified by N. I. Novozhiliv) Baidierstheria medialis (Kobet Kus); and fishes Lycoptera middendorfii Müll. Most of these species have also been observed in lower beds of the Vitim subformation, in the Kholbodzha and Tamcha areas.

Identified from unconsolidated siltstone and fine-grained sandstone of higher beds exposed at the head of the Ara-Ganga ravine [5] were Unio aragangensis Ch. Kol., U. continentalis, Ch. Kol., and Margaritana glabra Ch. Kol.

Union obrutschewi Mart. and Limnocyrena wangshihensis (Grab.) were identified by G. G. Martinson from the same interval in the Tamcha area.

In the Gusinoozersk trough, the Dabangorkhan subformation is made up chiefly of mixed-grain sandstones interbedded with siltstone; it carries up to six thick (10 to 40 m) beds of brown coal. The following species of freshwater pelecypods were collected from its various horizons in the Kholboldzha area: Limnocyrena transbaikalica Mart., L. shumilini (Ramm), L. kweichonwensis (Grab.), L. minoris Mart., L. sp. nov. I, typical of middle and lower beds of the Lower Cretaceous (Barrhemian-Aptian). The Vitim deposits which rest here on a weathered surface of Paleozoic and Precambrian crystallines and on lower Mesozoic extrusives are known within the Vitim plateau. The numerous but comparatively small developments of this subformation are grouped in four main areas: the Zaza trough, Vitim valley (from the Kholoy mouth to that of the Karenga), Amalat basin, and the Talaya valley.

Deposits now designated as the Vitim subformation were first studied in detail by K. S. Andrianov and I. A. Smirnov [1], who proposed their differentiation into the following five members, by lithology:

1) basal beds, about 50 m thick;

2) Baysin beds, about 65 m thick;

3) Sepkhinda beds, about 100 m;

4) arenaceous argillaceous beds, about 200 m;

5) sandy beds, about 60 m.

This subdivision of the Vitim subformation is valid only for the Vitim plateau, and only for the present. It should be noted that the Sepkhinda beds are fairly well correlative with the lower part of the arenaceous argillaceous section, so that only four groups of beds are clearly distinguishable.

The Vitim subformation begins with fanglomerate, and breccia, changing upward to finely clastic breccia, sandstone, siltstone, and shale, a total thickness of 50 to 100 m. Higher up, there are alternating siltstone, shale, marl, limestone, "paper-thin" bituminous slate, arkosic sandstone and gravel, total thickness up to 120 m. Still higher up there are 200 m of interbedded arkosic sandstone, black slaty to massive shale, and gravel. Calcareous sandstones in the lower part of this interval carry numerous phosphatized siderite concretions. A rich fauna of freshwater mollusks, phyllopods, ostracods, insects, and fishes has been collected by a number of students from various intervals of the Vitim subformation, in many troughs of the Vitim plateau. Some of the students of different groups of this fauna were O. M. Reis, I. G. Egger, B. I. Chernyshev, E. S. Rammelmeyer, V. V. Menner, G. G. Martinson, O. M. Martynova, etc.

Inasmuch as this fauna has been described on many occasions [2, 3, 8, 14, 15], we only list here (see Figure 2) the most typical species collected and studied by G. G. Martinson and the author.

In the Daban-Gorkhon trough, the Turga-Vitim formation rests unconformably on Lower Mesozoic extrusives and on Paleozoic granite and granosyenite. It is represented here by both the Vitim and Daban-Gorkhon regional subformations, conformable on each other. On the basis of lithology, the Vitim subformation can be divided into a basal conglomeratic unit horizon, up to 350 m thick, and a siltstone sandstone unit up to 500 m. The author has identified the following species of Lower Cretaceous freshwater pelecypods, from the lower part of the silt-sand unit: Limnocyrena altiformis (Grab.), L. selenginensis Mart., L. wiljuica Mart., L. wangshihensis (Grab.), L. kweichowensis (Grab.), L. pusilla (Reis), L. ovalis (Ramm.). The following mollusks were identified higher in the same unit: Limnocyrena subplana (Reis), L. wangshihensis (Grab.), L. pusilla (Reis), L. elliptica sp. nov., L. dabangorchonica sp. nov., L. ovalis (Ramm.), L. subelongata sp. nov., Probaicalia vitimensis Mart., Galba obrutschewii Ramm., G. Pervioides Mart., Gyraulus sibiricus (Dyb.) Mart., G. laevis (Alder), G. burjaticus sp. nov., Probaicalia rommelmejeri Mart., Lioplax sp.; phyllopods (identified by V. S. Zaspelova) Bairdestheria sinensis (Chi), Cyclograpta tingi Nov.; and Characeae Clavater nodosus Peck and C. mongolicus sp. nov.

Most of these species are typical of the Transbaykalian Vitim formation and are common in Lower Cretaceous deposits of Mongolia and China.

Deposits of the Dabangorkhon subformation are represented by alternating siltstone, shale, and sandstone, with four beds of brown coal, one of which is up to 80 m thick. However, that super-thick bed rapidly anastamoses, along the strike and dip. This subformation in the Daban-Gorkhon trough, is as thick as 450 m. Siltstone and fine-grained sandstone in its middle and upper intervals carry Limnocyrena transbaicalica Mart., L. schumilini (Ramm.), L. burjatica Mart., L. kweichowensis (Grab.), L. cf. tarbagataica Mart., Valvata turgensis Mart., Hydrobia lacustris, Limneae sp., Gyraulus sp., Radix sp., and Probaicalia sp. This assemblage of freshwater mollusks, widely distributed in the Dabangorkhon formation of Transbaykalia, characterizes higher Upper Cretaceous beds (Barrhemian-Aptian).

In the Kizhinga trough, the Turga-Vitim section is quite similar to that in the Daban-Gorkhon trough, except for a smaller thickness of brown coal beds and a poorer faunal assemblage (Figure 2).

Outside the Buryatian A. S. S. R., deposits of the Turga-Vitim formation are even more widespread in the Chita oblast' where they are known from the Kharanor, Shilka, Argun, and other troughs.

In Mongolia, deposits contemporaneous with the Turga-Vitim, lithologically similar to them, and carrying a similar faunal assemblage, have been designated the Lower Cretaceous Dzunbai formation, by V. G. Vasil'yev, V. S. Volkhonin, I. Ye. Turishchev, and K. B. Mokshantsev [2]. Moreover, the two regional subformations of the Dzunbai, the lower, dark gray, 700 to 800 m thick; and the upper green gray, coal-bearing, 400 to 500 m), roughly correspond to the regional subformations of the Turga-Vitim formation. Thus, the Vitim subformation may be correlated with the dark gray subformation, both being characterized by the same fauna and both carrying at their base the distinctive member of "paper-thin" bituminous slates and carbonate rocks. The upper subformations are coal-bearing in both Transbaykaliya and Mongolia.

SUMMARY

1. From the distribution of its freshwater fauna and from its lithofacies and structural features, the Mesozoic continental coal-bearing section of the western Transbaykal region (Transbaykalian coal measures) can be divided into three regional formations and four regional subformations (Figure 2).

Assemblages of freshwater species, characteristic of the regional subdivisions, are consistent on the whole throughout the western Transbaykalian area. The former lithologic diversity of each individual trough and even of parts of the same trough, can be reduced to these regional formations and subformations, divisible into local horizons and sequences by their lithology.

2. The troughs filled with these deposits originated in the crystalline basement at different times.

In that respect, they can be subdivided into three types: those having originated in a) Middle Jurassic; b) Upper Jurassic; and c) Lower Cretaceous (Figure 1).

The first type is developed exclusively in southwest Buryatia. Among them are the Gusinoozersk, Tugnuy, Chikoy-Khilok, and small Dzhida troughs. The largest among them, the Gusinoozersk, has undergone the longest subsidence and contains deposits of all three formations. Sedimentation in the Tugnuy, Chikoy-Khilok, and Dzhida troughs ended with the Ulanganga formation. The troughs formed in Upper Jurassic time are located northwest of the first type troughs (e. g., the Uda). Finally, Lower Cretaceous troughs are located still farther east and northeast. Among these are the Kizhinga, Daban-Gorkhan, Zaza, and the numerous troughs in the Vitim plateau; sedimentation in the Vitim plateau area was of the shortest duration, so that they are filled only with the Vitim deposits.

It is of interest, that these troughs often lie within a single major subsidence zone, where they replace one another, to the northeast. The most graphic example is the Gusino-Uda subsidence zone which houses troughs of all three types (Gusinoozersk, Uda, and Daban-Gorkhon). This suggests that Mesozoic subsidence of West Transbaykalian zones occurred to the northeast, progressively involving new areas.

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DISPERSED BITUMENS IN ALKALIC ROCKS OF THE KHIBINO PLUTON

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The Khibino nepheline syenite massif, the largest in the world, is located in the central part of the Kola Peninsula. Its periphery and center are made up of coarse-grained nepheline syenite, khibinite and foyaite. A series of uneven-grained nepheline syenite and rocks of the ijolite-urtite series with apatite-nepheline intrusions occur in the pluton in annular arcs. Enclosing rocks of the Khibino pluton are Archean gneisses, in the north and southeast; in the south and southeast, a body of greenstone rocks and the Imandra-Varzuga tuffaceous sedimentary formation, of Proterozoic age.

According to A. A. Polkanov [9] and N. A. Yeliseyev [4], this pluton is associated with a latitudinal fault which passes through the central part of the Kola Peninsula. The original roof of the pluton probably was represented by Imandra-Varguza rocks. The absolute age of the Khibino massif, as determined by various students (E. K. Gerling, V. G. Khlopin, I. D. Bespalova) working with the helium, argon, and lead methods, ranges from 275 to 350 million years.

Bituminous substances have been observed along with combustible hydrocarbon gases, in alkalic rocks of the Khibino massif. These bitumens are quite conspicuous in some rock samples, under a luminescent CVD-250 lamp; they fill up pores and very fine fractures in the alkalic rocks.

The elementary composition of chloroform extract of bitumen A, as well as the organic carbon content, has been determined for all intrusive rocks of the Khibino pluton and for two samples of the enclosing rocks. Group composition of the bitumen has been determined for several samples, along with infrared absorption spectrum analysis. The composition of the chloroform extract, and the organic carbon content, are shown in Table 1.

Bitumen was extracted from four samples (145, 145a, 135, and X-2) by the cold method, which does not extract all of it. Better results are obtained by the standard hot method, wherein the bitumen yield is increased by 100 to 200%.

In composition the Khibin bitumen is not different from that obtained from sedimentary rocks in oil and gas provinces; it is similar to crude oils (Figure 1; Table 2).

The content of bitumen and organic carbon in alkalic rocks is somewhat lower than in the sedimentary rocks; however, in isolated instances, the organic carbon content approach that in some sedimentary sequences classified as oil source beds.

In our study, carbon which appears to be dispersed in the rock and does not appear as a component of bitumen, should not be called organic, because it is associated with igneous rocks. It would be more correct to call it dispersed carbon. However, we shall continue calling such carbon by its conventional name, organic carbon, to avoid confusion.

It is interesting to compare the C_{org} content in rocks with the concentration of hydrocarbon gases in closed pores of the same rock samples (Table 3). The data cited show that the C_{org} content corresponds to the amount of hydrocarbon gases in pores of alkalic rocks, rising with its concentration. The same relationship has been observed, in four examples out of five, between the content of bitumen and hydrocarbon gases in rock pores.

Bituminous substances in rocks enclosing the Khibino pluton have not yet been adequately studied. Analyses of two rock samples show that Imandra-Varguza limestone and Archean granitoid gneisses carry two or three times less bitumen than the Khibino massif alkalic rocks. Their bitumen has much less carbon and more nonhydrocarbon components than the bitumen in the alkalic rocks.

Chemical bituminologic group analyses of the Khibino intrusive massif bitumen have shown

[1] Rasseyannyye bitumy shchelochnykh porod Khibinskogo plutona.

Table 1

The organic carbon content and the composition of bitumen A chloroform extract for the Khibino Tundra rocks

Sample No.	Rocks	Bitumen content % of rock	Organic carbon content	Composition C	H	N + O+S	C/H
	ROCKS OF THE KHIBINO ALKALIC MASSIF						
X5	Foyalite	0.0025	0.040	77.48	10.53	11.99	7.36
X140	Rieschorrite	0.0021	0.023	71.80	9.78	18.42	7.34
X7	Spotty apatite-nepheline	0.0015	0.010	76.50	11.20	12.30	6.83
145	Lenticular banded apatite-nepheline	0.00053*	—	77.71	12.35	9.94	6.28
145a	Same	0.0004*	—	79.80	11.63	S—0.47	6.8
X141	Urtite	0.0018	0.070	79.95	11.33	9.72	6.9
X142	Same	0.0027	0.030	75.59	10.00	14.41	7.56
135	Ijolite	0.0006*	—	81.02	13.55	S—0.19	5.9
X2	Khibinite	0.0013*	—	83.37	13.28	S—0.86	6.2
X2	Same	0.002	0.12	70.16	10.88	18.96	6.4
	ENCLOSING ROCKS						
X12	Granitoid gneiss	0.001	0.006	66.79	9.47	23.74	7.08
K10	Limestone	0.001	0.032	65.88	9.17	24.95	7.18
X11	Chlorite schist	0.003	—	61.46	8.80	29.74	6.9

*Bitumen extracted by the cold method.

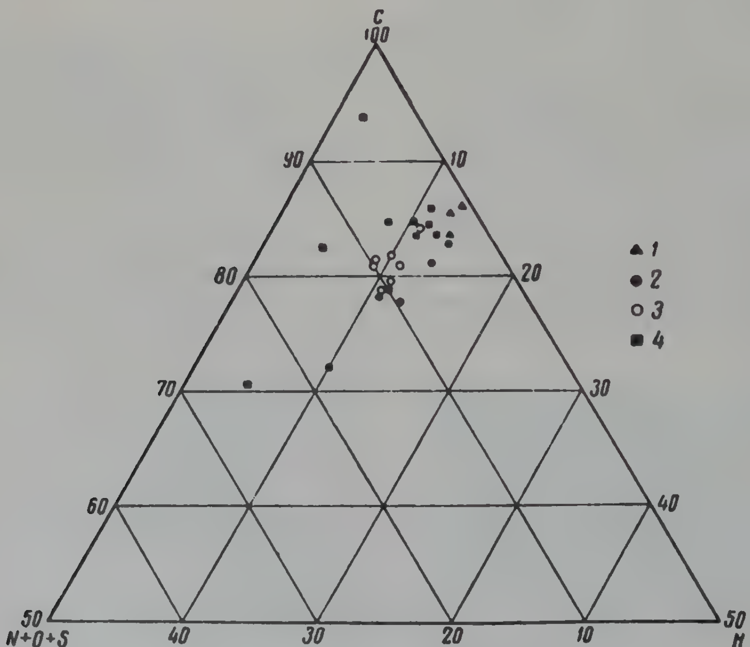

FIGURE 1. Diagram of the Composition of bitumens

1 - crude oil; 2 - bitumens from nepheline syenite; 3 - dispersed bitumens from sedimentary rocks in oil and gas provinces; 4 - other bitumens: asphalt, ozokerite, anthracite, hard and brown coal, albertite.

Table 2

Comparison of composition of crude oil, bitumen extracted from alkalic rocks, and dispersed bitumens in oil provinces (in %)

Industrial minerals and rocks	C	H	N+O+S	C/H
Crude oils	80—88	10—14	0.1—7	6—8
Bitumens from alkalic rocks of the Khibino pluton	77.59—83.37	9.78—13.55	3.37—18.42	6.2—7.6
Dispersed bitumens from sedimentary rocks of the Volga-Ural region (after V. A. Uspenskiy, [10])	77.5—77.9	10.6—10.8		
The Domanikovo-type rocks from Devonian carbonate section, Volga-Ural province (after Yu. N. Petrova, [8])	81.76	10.67	7.57	7.6
Shaley rock from Devonian terrigenous section, Volga-Ural province (after Yu. N. Petrova, [8])	79.49	10.69	9.82	7.4
Same, the Gorznyy Oblast' (after V. A. Uspenskiy, [10])	78.6—81.2	10.1—10.8		
Upper Tertiary deposits from the Sleptsovo area, Northeastern Caucasus (after V. S. Muromtseva and A. P. Shishkova, 1955)	78.56	10.80	11.36	7.2
Lower Cretaceous limestone, the Argun plateau, North Caucasus (after N. A. Yeremenko, 1957)	83.91	11.77	4.32	7.12

that it differs from the group composition of bitumen from sedimentary rocks of oil provinces, in its relatively low oil content, while the composition of isolated fractions fully corresponds to that of petroleum bitumens (Table 4).

Six samples of chloroform extract from the

Table 3

Comparison of the content of organic carbon, bitumen, hydrocarbon gases in the Khibino rocks

Sample No.	Rock	C_{org}	Chloroform extract	Hydrocarbon gas content in cm^3 to 1 kg of rock CH_4	C_2H_6	C_3H_8
	ALKALIC ROCKS					
X5	Foyaite	0.04	0.0025	19.02	0.087	0.12
X140	Rieschorrite	0.23	0.0021	55.05	0.903	2.06
X7	Spotty apatite-nepheline	0.01	0.0015	0.205	0.052	0.00
X141	Urtite	0.07	0.0027	62.18	3.02	0.25
X2	Trachytic khibinite	0.12	0.002	73.0	0.73	2.28
	ENCLOSING ROCKS					
X12	Granitoid gneiss	0.006	0.001	0.163	0.00	0.00
X10	Limestone	0.032	0.001	0.034	0.00	0.00
X11	Chlorite schist	—	0.003	0.077	0.00	0,00

Table 4

Group composition of bitumen in the Khibino Tundra rocks

Sample Nos.	Rocks	Group composition				Fractional Composition (Elements)			Fractions
		oils	benzene tars	alcohol-benzene tars	asphaltite	C	H	N+O+S	
X5	Foyaite	29.19	21.93	20.51	28.23	83.10	13.72	3.12	Oils
						71.40	10.10	18.50	Benzene tars
						67.00	9.79	23.21	Alcohol-benzene tars
						56.71	7.44	35.85	Asphaltites
X6	Rieschorrite	28.00	21.62	35.11	10.5	82.54	13.29	4.17	Oils
						74.00	9.98	16.02	Benzene tars
						65.00	9.40	25.60	Alcohol-benzene tars
						60.10	8.20	31.70	Asphaltite
145	Lenticular-banded apatite-nepheline	14.98	43.24	34.81	6.00	82.96	10.26	6.78	Oils
						77.45	9.31	13.24	Benzene tars
						69.05	8.93	22.02	Alcohol-benzene tars
X142	Urtite	22.00	28.96	29.16	19.87	83.84	13.43	2.73	Oils
						72.00	9.67	18.27	Benzene tars
						69.01	8.50	21.40	Alcohol-benzene tars
						64.10	8.50	23.40	Asphaltite
X2a	Khibinite	26.60	17.61	33.11	14.5	81.00	12.34	6.66	Oils
						71.69	9.66	18.65	Benzene tars
						65.41	9.20	25.39	Alcohol-benzene tars
						61.50	8.38	30.12	Asphaltite
X12	Granitoid gneiss (Archean)	18.96	17.91	40.00	17.51	77.26	11.63	11.71	Oils
						70.50	9.98	19.5_	Benzene tars
						66.05	9.45	24.50	Alcohol-benzene tars
						60.34	8.00	31.66	Asphaltite

Khibino pluton alkalic rocks and two samples of the enclosing rocks were studied by the infrared spectroscopic method. Fractions (oils, benzene tars, alcohol-benzene tars) were analyzed in three samples.

Spectra were taken with the single-ray spectrometer IKS-11, with a halite prism, on a sample 0.01 mm thick. The spectra of chloroform extracts are presented as originally recorded (without conversion to % of passing light).

The samples of bitumen extracted from foyaite (X-5) and khibinite (X-2) show the absorption bands of high molecular n-structure paraffins with $C_{29} - C_{31}$ carbon atoms in the chain with sufficient clarity (Figure 2). The number of carbon atoms in paraffin chains of the bitumens under study was determined also electronographically, by B. A. Anurov. According to him, the number of carbon atoms in the chain ranged from C_{27} to C_{29}.

Samples of bitumens extracted from rieschorrite, urtite, and trachytic khibinite, with paraffin structures similar to those in previous

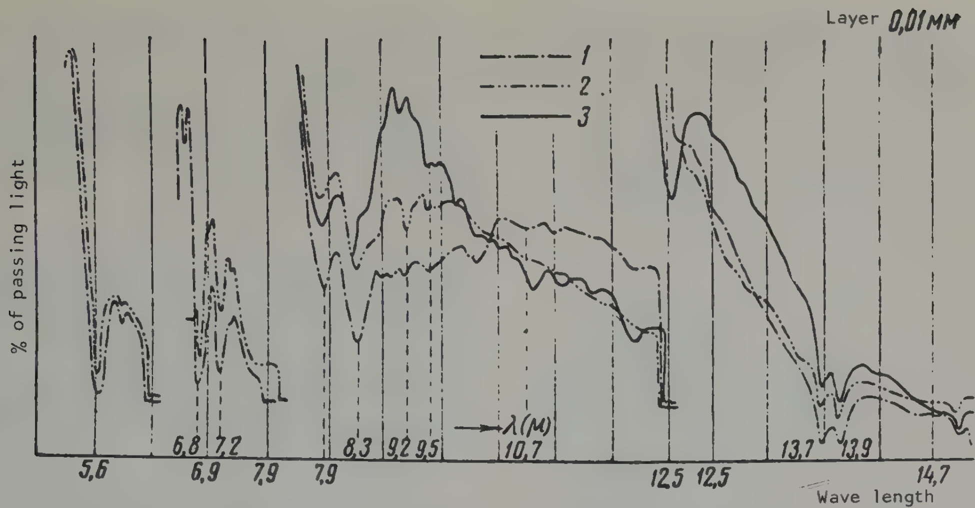

FIGURE 2. Absorption spectra of bitumens extracted out of khibinite and foyaite

1 - bitumen X-2 from khibinite; 2 - bitumen X-5 from foyaite; 3 - bitumen 86 from Tertiary claystone (Upper Maykopian, Tashla 7).

samples, exhibited distinct absorption bands of aromatic hydrocarbons ($\lambda_1 = 6.24\ \mu$; $\lambda_2 = 12.4\ \mu$; $\lambda_3 = 13.5\ \mu$).

In the bitumen from limestone and granitoid gnesiss, the presence of paraffin hydrocarbon chains is difficult to detect. While their traces are present in the limestone bitumen spectrum, they are nonexistent in the granitoid gneiss-bitumen (Figure 3).

The middle part of the spectrum, where both the individual functional grouping and the molecules themselves, the components of tars, aromatics, and oxygen compounds are subject to flutations, exhibits both a complete similarity and some differences in the absorption bands. For example, bitumens of khibinite (X-2) and foyaite (X-5) exhibit a similarity in their distinct absorption bands 5.7–5.8 μ, 7.9 μ, and 8.5–8.8 μ, typical of functional groups of carbonyl C = O, carboxyl COOH, or the C – O – C grouping of compound esters. The simultaneous presence of intensive bands 5.9 μ and 8.5–8.8 μ may be assigned most likely to the compound esters of acids. The appearance of these bands may also be caused by fluctuations in the structure of compound esters-sterols.

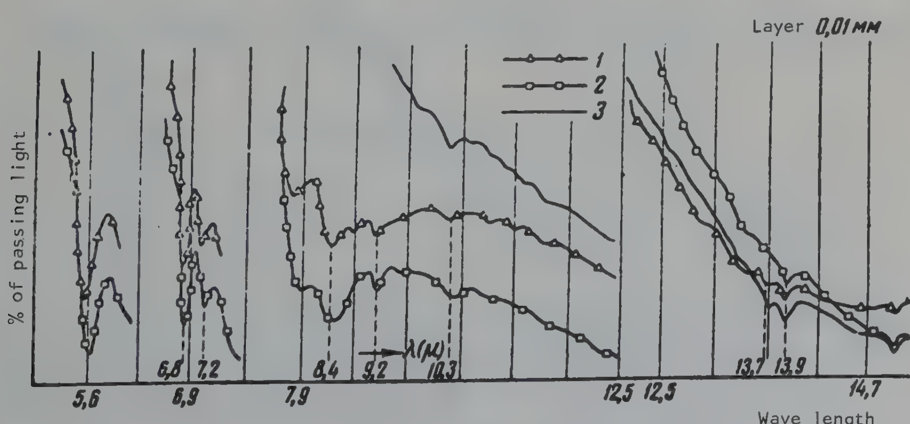

FIGURE 3. Absorption spectra for bitumens extracted from limestone and granitoid gneiss

1 - bituman Xz-10 from limestone; 2 - bitumen X-12 from granitoid gneiss; 3 - bitumen 311 from the crystalline basement.

These bands are quite distinct for fractions of benzene tars in bitumens from foyaite and urtite; they are characteristic also for benzene tars from bitumen C in Tertiary deposits.

The difference between bitumens X-2 (khibinite) and X-5 (foyaite) is in the absorption bands $\lambda_1 = 10.3-10.4\ \mu$; $\lambda_2 = 10.8-10.9\ \mu$; $\lambda_3 = 3.0\ \mu$; and $\lambda_4 = 3.7\ \mu$, which appear when carbonic acid are present in samples. For comparison, Figure 2 shows the spectra for the Khibino massif bitumen samples and that for Tertiary clays (Upper Maykopian, Tashla test hole No. 7). The coincidence of the principal absorption bands for bitumens from sedimentary and alkalic rocks (khibinite and foyaite) demonstrates graphically the similarity of their group composition (Figure 2). The spectra of bitumens from other Khibino massif rocks, rieschorrite, urtite, and trachytic khibinite, show the presence of benzene and polycyclic aromatics and a coincidence of aromatic and paraffin structures with those of the sedimentary rock bitumen (Figure 4). Here, a certain quite distinct in the spectra of bitumens from trachytic khibinite (X-2B) and rieschorrite (X-6), these bitumens are similar to those from shale. A spectrum of bitumen from a Carboniferous limestone, Figure 2, is identical with that for samples X-2B and X-6, in the hydrocarbon segment; and differs sharply from them, in the nonhydrocarbon segment.

Absorption spectra of Archean granitoid gneisses and Imandra-Varguze limestones enclosing the Khibino massif differ in composition from those of alkalic rocks. These rocks carry no bitumen. Their nonhydrocarbon fraction is expressed by a heavy unbroken band in the 8.4 to 8.7 μ range and appears to be related to the carboxyl or the OH group of fatty acids with a long chain.

As a result of studying the bitumens from the Khibino pluton by the infrared spectroscopic method, their typical features can be listed as follows:

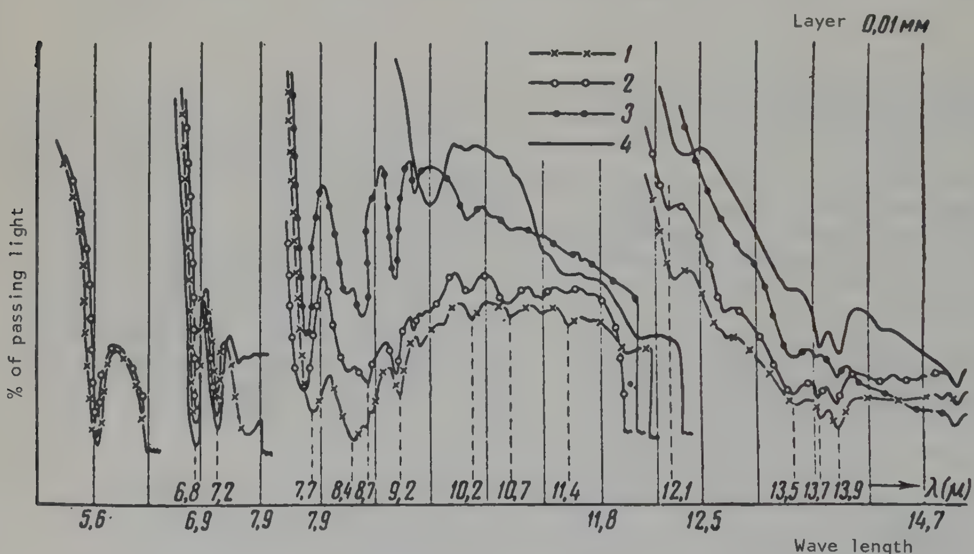

FIGURE 4. Absorption spectra for bitumens extracted from trachytic khibinite, rieschorrite, and urtite.

1 - bitumen X-2-6 from trachytic khibinite; 2 - bitumen X-6 from rieschorrite; 3 - bitumen X-142 from urtite; 4 - bitumen 214 from Carboniferous limestone.

redistribution in the intensities of the absorption bands, as compared with the spectrum in Figure 2, has been observed in the middle part of the spectrum. The double band, 8.5–8.8 μ is more conspicuous; the 9.3 μ band is well defined, possibly because of the presence of aromatic grouping CO — RO, of compound esters (of the phtalate and benzoate types).

As shown by the 11.45 μ absorption band,

1. Bitumens X-5 (foyaite) and X-2 (khibinite) carry high molecular paraffins of n-structure, with $C_{27} - C_{31}$ carbon atoms. Certain isostructural paraffins have also been observed; they branch out considerably in bitumen X-2.

2. The bulk of the bitumen is represented by tars with functional groupings = CH — CO — O — R, of the composition of compound esters of the acrylate, fumarate, and maleate types.

3. The presence of the compound sterol ester grouping CO — O is not ruled out.

4. There is an almost complete similarity in the absorption bands of the hydrocarbon fraction in bitumens from the Khibino massif rocks and those of the sedimentary-rock bitumens.

5. Present along with the normal-structure paraffins in bitumens extracted from urtite and rieschorrite are aromatic polycyclic hydrocarbons, of the same type as hydrocarbons from bitumens in sedimentary rocks.

6. Bitumens from granitoid gneisses and limestones enclosing the pluton are quite different from those in rocks of the Khibino massif. They carry no hydrocarbons, while their nonhydrocarbon fraction is characterized by the presence of long chain fatty acids.

The following components have been noted in the study of bitumen fractions from trachytic khibinite (X-2-B), rieschorrite (X-6), foyaite (X-5), and urtite (X-142):

a) Oils + Petroleum Ester Tars

The spectrum characteristics of oils from bitumens in trachytic khibinite and rieschorrite are shown in Figure 5. The oils contain high molecular paraffins of the n-structure, with an addition of naphthenes and isostructural paraffins. The spectra of the bitumen X-2-B oils show distinct absorption bands 12.3 μ and 12.6 u, typical of the tri-tetra-replacement of the benzene ring; the presence of cyclopentylhexyl-benzenes is also possible. A complete similarity in spectra for oils from bitumens in the Khibino alkalic rocks and for oils from sedimentary rocks has been observed.

It was impossible to describe adequately the oils from bitumens X-5 and X-142, because of the small amount of them in samples.

b) Benzene Tars

The spectra of benzene tars from bitumens X-5, X-6, and X-142 are quite similar, thus indicating a complete similarity of their component functional groups (Figure 6).

The spectrum of benzene tars X-142 coincides almost completely with that of diisoctylphthalate crude oil from the Seven Rivers formation.

A strong 10.3 μ band, conspicuous in the spectrum of benzene tars from sample X-142, in combination with a number of other bands, may be assigned to heterocyclic hydrocarbons of the pyramidine type, or of a phthalate type with CO — OR grouping. A strong similarity has been observed between the benzene-tar spectra for all alkalic rock samples studied and benzene tars from sedimentary rocks.

c) Alcohol-Benzene Tars

The spectrum of alcohol-benzene tars, unlike that of the benzol tars, exhibits a strong

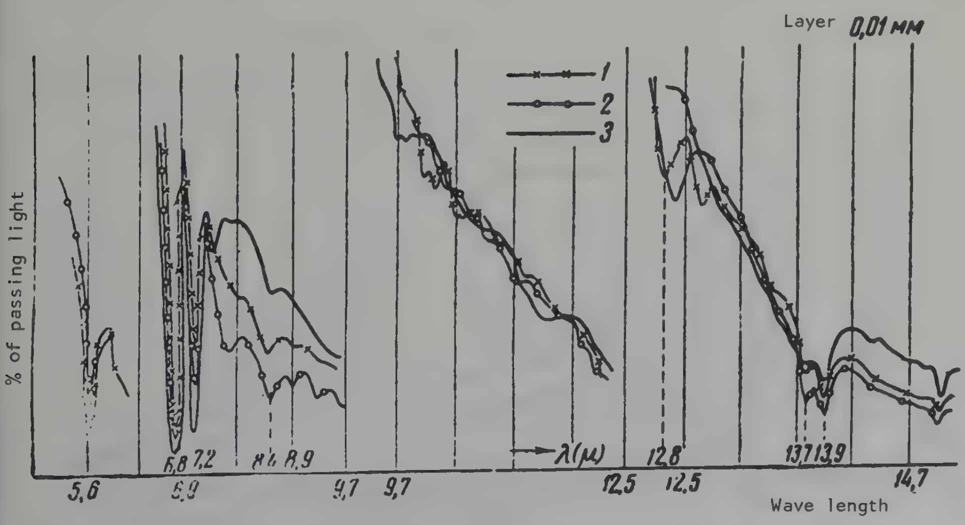

FIGURE 5. Absorption spectra for fractions of oils from bitumens X-2-B (khibinite), X-6 (rieschorrite), and analysis 195 (dolomite).

1 - oils from bitumen X-2-B (khibinite); 2 - oils from bitumen X-6 (rieschorrite); 3 - oils from bitumen 195 dolomite (Kungurian stage).

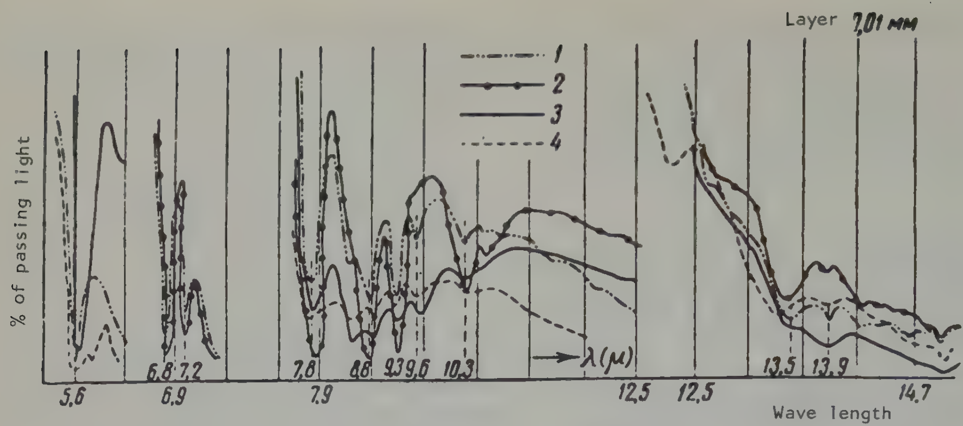

FIGURE 6. Absorption spectra for fractions of benzene tars from bitumens X-5 (foyaite) and X-12 (urtite).

1 - bitumen X-5 from foyaite; 2 - bitumen X-142 from urtite; 3 - bitumen C, analysis 59 from Tertiary clays (Lower Sarmatian); 4 - bitumen, analysis 139 from Carboniferous shales (Stalinogorsk horizon).

3.0 μ band typical of the OH or NH group. It seems to indicate the presence here of high molecular spirits of the sterol group, or of aromatic spirits (Figure 7).

The study of bitumens from the Khibino pluton alkali rocks, because of the small number of samples analyzed, should be regarded as preliminary. A more comprehensive study will be carried on in the future.

The data for bitumen dispersed in the Khibino alkalic rocks positively demonstrate that there is every reason to assign it to the petroleum series. This bitumen contains paraffin and aromatic hydrocarbons as well as oxygen, nitrogen, and sulfur compounds. Its group analyses and element analysis are quite similar to that of bitumens dispersed in sedimentary rocks.

Besides the solid bitumens, the Khibino alkalic rocks carry genetically associated hydrocarbon gases. Therefore, in considering the regularities in the distribution of bitumen in rocks of the intrusive massif, we should study them in combination with gaseous bitumens.

The gas phase of Khibino alkalic rocks is represented by combustible gases, mostly

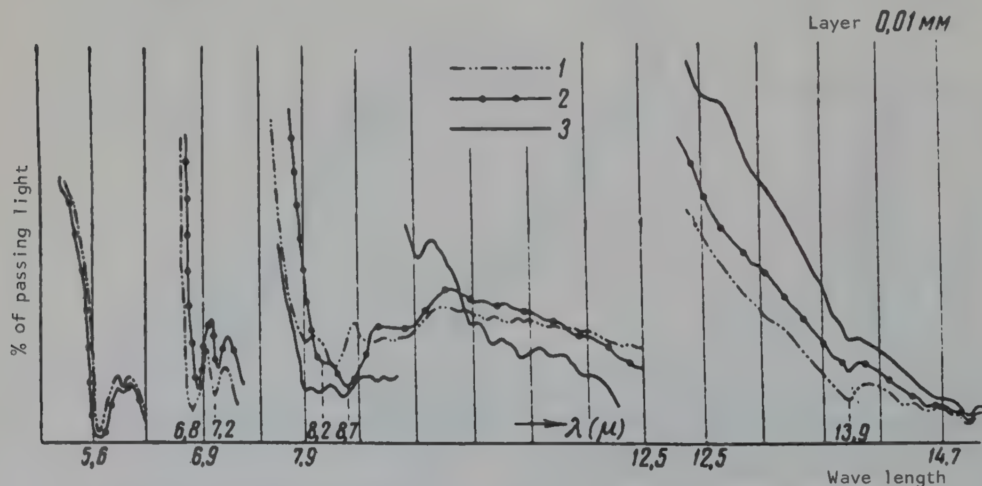

FIGURE 7. Absorption spectra for fractions of alcohol-benzene tars from bitumens X-5 (foyaite) and X-142 (urtite).

1 - bitumen X-5 from foyaite; 2 - bitumen X-142 from urtite; 3 - bitumen, analyses 37 + 38, from Tertiary deposits (Upper Maykopian).

hydrocarbons, as well as by a small amount of carbon dioxide and nitrogen, with occasional ammonia. Present in the combustible gases are methane, ethane, propane, less commonly butane, and occasionally isobutane, with small amounts of carbon monoxide and hydrogen. At depths, the gases occur in fractures, pores, and crystal hollows.

Hydrocarbon gases are present only in alkalic rocks of the intrusive massif and are virtually absent in the enclosing rocks: Archean granitoid gneisses and the Proterozoic Imandra-Varzuga sedimentary extrusive formation.

The content of hydrocarbon gases in rock pores may be considerable. In two samples from test hole No. 168, it was determined as 240. 20 and 170. 82 cm^3/kg of rock. The hydrocarbon gas content in pores of alkalic rocks varies depending on their mineral and chemical composition. A study of minerals in the Khibino alkalic rocks has shown that the hollows in their crystals contain hydrocarbon gases.

This relationship between the hydrocarbon gas content and the chemical composition of alkalic rocks, as well as the presence of these gases in crystal hollows as against their lack in the enclosing rocks, unquestionably indicates that these gases are syngenetic with the rocks which carry them. The origin of hydrocarbon gases in alkalic rocks is related to the processes of inorganic synthesis. They were formed during the intrusion, in crystallization of the magmatic melt, under changing thermodynamic conditions. The source of carbon in inorganic synthesis may have been carbon oxide, quite stable at high temperatures, as well as the dispersed elementary carbon. Water, present in a magmatic melt as superheated steam, may have been an adequate source of hydrogen.

The synthesis of hydrocarbons was promoted by the presence of catalysts, with aluminum silicate the most powerful among them. The latter is present in large amounts, in alkalic rocks. Another factor was the presence of a tight seal which promoted a slow crystallization of rocks and prevented large volumes of gases generated, from escaping to overlying formations and to the atmosphere.

Hydrocarbon gases could have been formed in a synthesis of elementary carbon and hydrogen: $C + 2H_2 \rightleftharpoons CH_4$. Under laboratory conditions, this reaction proceeds at a temperature of 1200° C; in the presence of catalysts, it may take place at lower temperatures (down to 475°). Methane can be formed also in a reaction between carbon oxide and hydrogen:

$$4CO + 8H_2 \rightleftharpoons 2H_2 + CO_2 + 3CH_4$$

As the intrusion progressed, there was a gradual pressure and temperature drop, which substantially affected the chemical processes underway. It appears that the trend of these reactions was from simpler to ever more compound molecules. The formation of methane at the initial stages was followed by that of ethane, propane, butane, etc. Later, at lower temperatures and pressures, in the absence of free oxygen, and in the presence of mineral

Table 5

Composition of gases in minerals of pegmatitic bodies in the ijolite-urtite intrusive complex

Minerals	Gas content, in cm^3 per kg. of rock						
	H_2	CH_4	C_2H_6	C_3H_8	C_4H_8	CO	CO_2
Nepheline	0.155	34.07	0.248	0.723	0.084	0.06	1.04
Feldspar	0.025	13.69	0.102	0.600	0.0	0.00	0.0
Aegirine	0.23	9.29	0.205	0.344	0.0	0.01	0.0
Eudialite	3.40	6.33	0.151	0.664	0.0	0.091	3.01
Sphene	0.20	14.67	0.080	0.488	0.0	0.081	0.81
Apatite	0.63	3.34	0.189	0.440	0.0	0.04	1.66
Average gas content in the Khibino intrusive and lateral rocks (in cm^3 per kg. of rock)							
Intrusive alkalic rocks	1.72	37.98	0.54	0.29	0.02	1.12	9.38
Archean granitoid gneisses	5.39	0.163	0	0	0	0.45	12.49
Imandra-Varzuga sedimentary extrusive rocks	2.52	0.35	0	0	0	0.38	13.7

catalysts, an ever more complex synthesis may have led to the formation of liquid and solid bitumens. Such a synthesis may have been strongly affected by postmagmatic processes which altered the originally crystallized substance. The nonhydrocarbon components of bitumens, too, could have been formed in an inorganic synthesis.

Thus, the bitumen in alkalic rocks of the Khibino intrusive is the product of a single process of formation, from the simplest molecules of hydrocarbon gases to compound high molecular bodies.

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METHODS

APPLICATION OF ULTRASONIC TECHNIQUES IN MINERAL ANALYSIS OF SEDIMENTARY ROCKS[1]

by

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Ultrasonic techniques, now widely used in various fields of science and technology, are beginning to move in steadily on such geologic disciplines as mineralogy, petrography, micropaleontology, and pedology. Their application has to do with a number of specific although quite essential problems in the preliminary processing of material (rocks, minerals, microorganisms, etc.) for specialized analyses. The success of ultrasonic techniques in the processing of rocks and minerals opens up new methods of application. It is of interest that the early attempts at dispersion were on homogeneous media, monomineral suspensions [14-16].[2] Later on, ultrasonic techniques were used in the disintegration of heterogeneous media, rocks with assorted spores and microorganisms [17]. One year after that, W. Wetzel [18] used the ultrasonic field not only in disintegrating heterogeneous ancient and modern soils but also in spearating "pure" structure-forming components from various soils. Each field of application of ultrasonic techniques has features of its own and warrants separate treatment. This paper summarizes certain published material on the application of ultrasonic techniques in the study of rocks and minerals and describes the initial results of ultrasonic dispersion and disintegration, obtained in the Authigenic Mineralogy Laboratory, Geological Institute, U. S. S. R. Academy of Sciences.

Although the literature on ultrasonics is quite voluminous (for instance, L. Bergman's monograph [2], published in 1954, cites 5150 sources), many processes observed and often made use of, have not yet been satisfactorily explained. It is generally admitted that the practice of ultrasonic techniques is considerably ahead of development of the underlying theoretical principles.

For a better understanding of the results and for a more rational planning of the use of ultrasonic techniques in geologic studies, we shall discuss briefly some phenomena in the field of ultrasonics.

1. A Brief Description of Some Processes in the Field of Ultrasonics [1, 2, 4, 5]

Ultrasons of an intensity approximately up to 3 wt/cm^2 are ordinarily used at low frequencies (about 25 kilocycles), and approximately up to 30 wt/cm^2 at high frequencies (about 1 megacycle).[3] The ultrasonic field in water is characterized by respective displacements of ~ 1.5 and $\sim 0.1\ \mu$; velocity, ~ 20 and ~ 65 cm/sec; acceleration, $\sim 3 \cdot 10^3$ and $\sim 400 \cdot 10^3$ cm/sec^2; pressure, ~ 3 and ~ 10 atm; and the average gradient of sonic pressure, ~ 2 and ~ 250 atm/cm. These properties of ultrasons bring about a number of interesting phenomena.

The phenomena of cavitation are of particular importance in our understanding of the results of our experiments. Each point of a medium through which an ultrason is passing is compressed during one half-period and expanded during the other half. In the expansion of a fluid beyond its critical point, its continuity is broken up to form a hollow which may be filled by solution gases, volatile additions, and molecules of the fluid. A degassing of the fluid takes place. This break in continuity in the ultrasonic field can last only a very short time — the expansion half-periods ($\sim 2 \cdot 10^{-5}$ sec at

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[1] Primeneniye ul'trazvuka pri mineralogicheskom analize osadochnykh porod.

[2] Reference will be made, as a rule, only to general monographs and a number of recent original works not mentioned in them.

[3] 1 megacycle = 10^3 cycles; 1 kilocycle = 10^6 cycles.

25 kilocycles, and ~ $5 \cdot 10^{-7}$ sec at 1 megacycle); in the following compression period, the continuity of the degassed fluid is restored and the gas bubbles disappear. Thus, the hollows and bubbles in an ultrasonic field are formed and destroyed with ultrasonic frequency; this is the cavitation process.

Experimental values of volume strength of water are scattered over a wide range, from zero to ~ 280 kg/cm^2 (the theoretical value, ~ 3000 kg/cm^2). This apparently is the explanation of the fact that cavitation is determined by local points of weakness, the so-called centers (or nuclei) of cavitation. They are represented by fluctuations in the density, temperature, dissolved gas, or additions: minute gas bubbles, foreign bodies, more specifically solid particles of hydrophyllic, fractured, or porous substances. It has been established that the higher the frequency, the more intensive the ultrasons must be in order to achieve cavitation. In degassed water, an intensity of more than ~ 0.16 wt/cm^2 is adequate at a frefrequency of 15 kilocycles; it must be ~ 300 wt/cm^2 at 500 kilocycles, and ~ 50,000 wt/cm^2 at 3.3 megacycles.

It should be kept in mind that some cavitation bubbles are not destroyed at once but persist for some time during which they pulsate and move about, accumulating in fractures, pores, and shells of the irradiated body, where they remain until destroyed [3].

Cavitation may bring about a number of secondary phenomena, such as dispersion of solid bodies in an ultrasonic field.

The destruction of bubbles may develop powerful hydraulic shocks, up to several thousand atmospheres. The destructive radius of a cavitation depends on the intensity and frequency of the ultrason. Another view of the mechanics of cavitational disintegration [5] holds that the surfaces of solid bodies always have microfractures; in hydraulic cavitation shocks (in the compression half-periods), the fluid is squeezed into these microfractures; in the half-periods of lower pressures, the fluid flows out of the microfractures at a high differential pressure (up to several thousand atmospheres) and erodes the solid surface. Thus, although there is general agreement that cavitation is the factor in the dispersing of solid bodies within an ultrasonic field, its mechanism appears to be a complex one, consisting of a number of processes whose effect depends on the experimental conditions (frequency, intensity, the propagation medium, temperature, pressure, etc.).

2. The Equipment

In our experiments, we used the GU-3 ultrasonic generator, manufactured by the Moskip factory in 1957. The wiring of the first model of this generator is described in detail, in V. M. Friedman's monograph [10]. Its capacity is 1.8 kwt. It has five transmitters with frequencies of 22, 300, 600, 750, and 1000 kilocycles. The 22 kilocycle transmitter is a standard magnetostriction vibrator with a radiation area of 70 cm^2 (square with sides 8.4 cm long). The ultrason intensity, ~ 3 wt/cm^2. The magnetostrictor radiation is water cooled. High frequency radiators are quartz disks operating at their fundamental resonant frequencies. The radiation area of the quartz resonators is ~ 10 cm^2 and the sound intensity is ~ 30 w/cm^2. The quartz transmitters in their settings are placed in a transformer oil bath; a glass beaker with substance to be irradiated is placed over the transmitter. Each quartz transmitter comes with a beaker which has a bottom with a precise thickness of several half-wave lengths; thus it is in resonance with the transmitter and is in effect transparent to ultrasons, which provides for a maximum intensity within the beaker. In further experiments, the cyclinders with "tuned-up" bottoms were replaced with universal cylinders having perlon bottoms.[4] The thin perlon film, much thinner than the ultrasonic wave is long (0.06 mm), turned out to be fairly strong and almost "transparent" to ultrasons. The magnetostrictor was equipped with an exponential focusing cone [6], half the wave-length long, which intensified the ultrason by approximately a factor of 2.5.

The ultrason intensity at a frequency of 22 kilocycles was measured with an indicator consisting of a glass rod (L = 15 cm; d = 5 mm) with one end in the ultrasonic field and the other having a barium titanite plaque attached to it, to measure the variable stress. The indicator is placed in a metal container, for protection.[5]

3. Disintegration of Heterogenous Media

a) Published Data

W. Wetzel is poineer in the field of disintegration of consolidated rocks [18]. He conducted the first experiments in rock disintegration for obtaining micropaleontologic remains. Preliminary ultrasonic processing was done on pea-size rock fragments (sandstone, siltstone, shale, diatomaceous rocks, etc.) carrying assorted microfossils (foraminifera, ostracods, radiolaria, etc.). The crushed rock was placed in a beaker with water and then introduced into the ultrasonic field. The experimental conditions were standard (frequency, 800 kilocycles; intensity, 7 wt/cm^2; the irradiation time, a few minutes). After the

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[4]The construction of cylinders with perlon bottoms, along with a supply of perlon material, was kindly persented to us by Doctor H. Ludwig (Halle University, G.D.R.).

[5]Designed by the Acoustic Institute, the U.S.S.R. Academy of Sciences; the N.L. Rosenberg Laboratory kindly demonstrated to us the indicator operation.

irradiation, the beaker content was rinsed, sorted into fractions, and inspected under the binocular microscope. Well-processed micro-organic remains have been observed along individual mineral grains, in almost all attempts. Of special interest are the fine ostracod tests separated from opal-silica cemented diatomaceous rocks.

In the Mineral Fuel Institute of the U. S. S. R. Academy of Sciences, ultrasonic separation of spores and pollen from consolidated rocks was done under pressure [9]. The sandstones were first saturated with an aqueous solution of HC1; tough carbonaceous shales, with a water-alcohol mixture. The crushed rock was then placed in a cyclinder with the same fluid, was pressed somewhat with a plunger, and the cylinder was placed on the irradiator.

b) Experimental Data

The Laboratory experimented on disintegration of quartzitic glauconitic siltstone from the Pachelma trough Riphean beds drilled through by the Serdobsk control test, at 1462 m (samples 61/56 and 60/56). The purpose of the experiments was to break up the rock into its structural components for the subsequent separation of glauconite grains, as well as to determine the optimum ultrasonic conditions of irradiation and a method for preliminary processing of rocks.

First, a few words on the microscopic texture of the rock in question. It is represented by a well-sorted coarse-grained siltstone with a typical regenerated mosaic texture. Its terrigenous fragments, 0. 08 to 0. 09 mm, are quartz grains with traces of albite, orthoclase, and isolated grains of microcline. The grains are closely compressed, with smooth contacts (conformable) or are separated by rectilinear sutures, in the adjacent regenerated envelopes. Collomorphic glauconite grains are of the same size as the clastic fragments of the groundmass. Homogenous rounded to oval glauconite aggregates are evenly fused in the rock mosaic; they are less common in chain-like accumulations along the bedding planes.

In all experiments described below, the rock was first crushed in a mortar and sorted out by fractions; it was then placed in a 100 milliliter glass beaker, with 50 milliliters of water. The beaker was placed in the ultrasonic field.

Experiment 1. Rock disintegration as a function of ultrasonic frequency. Fraction 0. 25 to 0. 1 mm (1 gm) was irradiated for 5 minutes by frequencies of 22, 300, 500, 750, and 1000 kilocycles (Figure 5-a). The sample was then rinsed, dried, and passed through a 0. 1 mm mesh sieve. The percent of disintegrated grains (i. e., those having passed through the 0. 1 mm mesh) with relation to the weight of the original sample was determined from the latter and from the weight of grains having passed through the 0. 1 mesh. This criterion was selected because of the uniformity of the 0. 08 to 0. 09 mm fraction grains, with the binocular showing only a few combined growths of disintegrated components (Figure 5-b). The experimental results are illustrated by the curve (Figure 1) which shows that the maximum disintegration takes place at a minimum irradiation frequency (22 kilocycles), notwithstanding the fact that the ultrasonic intensity at that frequency is about ten times lower (~ 3 wt/cm^2) than at higher frequencies (~ 30 wt/cm^2). However, the disintegrating effect is stronger at higher intensities, as demonstrated by the following experiment.

Experiment 2. Rock disintegration as a function of ultrasonic intensity. Samples of fraction 0. 1 to 0. 25 mm (1 gm) were irradiated for 5 minutes, at a frequency of 22 kilocycles, of various intensities: ~ 1.5, ~ 3, and ~ 7 wt/cm^2. A commercial magnetostrictor with an exponential focusing cone was used for the highest intensity. The experimental results are illustrated by the curve (Figure 2) which shows that the disintegrating effect grows with the ultrasonic intensity. A binocular inspection of irradiated samples shows that the qualitative characteristic of disintegrated grains is virtually independent of intensity.

Experiment 3. Rock disintegration as a function of grain size. Fractions 0. 5 to 1. 0, 0. 25 to 0. 50, and 0. 1 to 0. 25 mm (1 gm each) were irradiated for 5 minutes, with a frequency of 22 kilocycles, at an intensity of ~ 3 wt/cm^2. The samples were then dried, passed through 0. 5, 0. 25, and 0. 1 mm mesh, and weighed. The results are shown by the curve in Figure 3 which shows that the fraction with the smallest grain size (0. 25 to 0. 1 mm) is the best disintegrated. However, the quality of grains so disintegrated is not always uniform.

Experiment 4. Rock disintegration as a function of the duration of ultrasonic irradiation. Fraction 0. 1 to 0. 25 mm (15 gm) was irradiated for 5 minutes at a frequency of 22 kilocycles with an intensity of ~ 3 wt/cm^2. After a sorting of the irradiated sample and a weighing of nondisintegrated grains (left on the 0. 1 mm mesh sieve), the latter were subject to repeated irradiation. The irradiated sample was sorted out, weighed, and the fraction left in the sieve was irradiated once more. This operation was repeated ten times. The results are shown in Figure 4. The curve shows that about half of the initial sample disintegrated in these ten attempts, with about 25% having

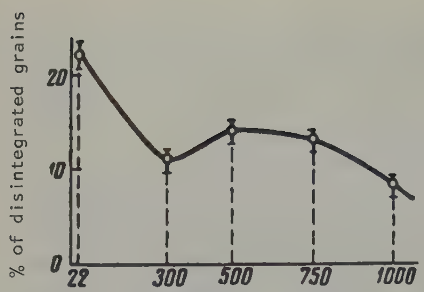


FIGURE 1. Disintegration of glauconitic quartzite as a function of ultrasonic frequency.

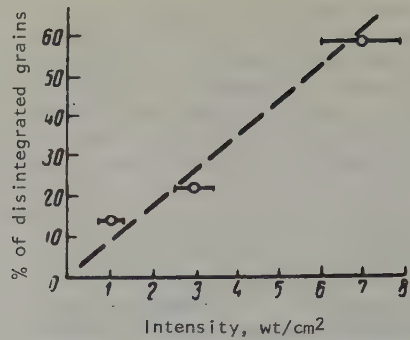


FIGURE 2. Disintegration of glauconitic quartzite as a function of ultrasonic intensity.(22 kilocycles).

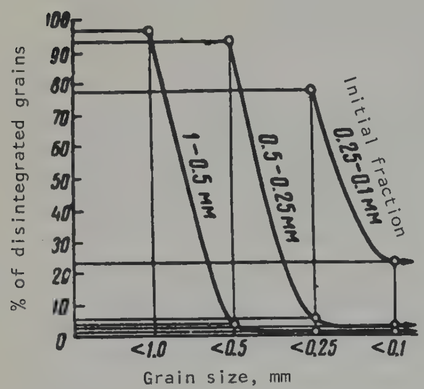


FIGURE 3. Disintegration of glauconitic quartzite as a function of the initial crushing of rock into different fractions.

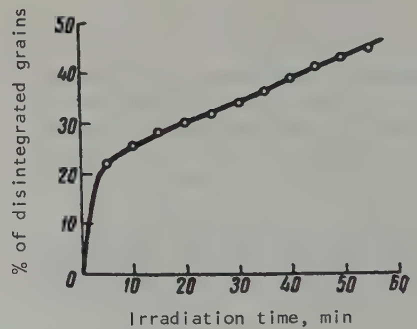


FIGURE 4. Disintegration of glauconitic quartzite as a function of the duration of the ultrasonic irradiation (22 kilocycles).

disintegrated in the first five-minute irradiation. The subsequent irradiations disintegrate small and about equal amounts (2 to 3%) of the original sample.

We note in conclusion that thin sections of this rock also were exposed to the ultrasonic field (~ 22 kilocycles, ~ 3 and ~ 7 wt/cm^2), after which they did show amorphous cavities throughout the section, virtually without any regard to the grain boundaries. The number of these caverns and their average size and depth increase with the intensity and duration of ultrasons.

4. Dispersion of Homogenous Media

a) Published Data

Clay suspensions processed by ultrasons as a preliminary to granulometric analysis or to an electron-microscopic study were used as homogenous media. Obtaining the suspension with primary dimensions of clay particles necessary in the study presents considerable difficulties, in connection with agglomeration phenomena which emerge because of the small size of clay particles and because of their high surface energy. Studies in this field by French [15, 16], American [11], and German [12, 15] scientists have shown that none of the mechanical methods can achieve the degree of perfection attained in the dispersion of suspensions by the ultrasonic method [5]. However, the mechanism of ultrasonic dispersion for clay rocks of different grain sizes and mineral composition, as well as the optimum frequency, intensity, and duration of ultrasonic irradiation, are not adequately known beyond the initial steps.

A. Mathieu and G. Lavavasser have determined, that the maximum dispersion of kaolinite suspension takes place at a frequency of 960 kilocycles [15]. That appears to be due

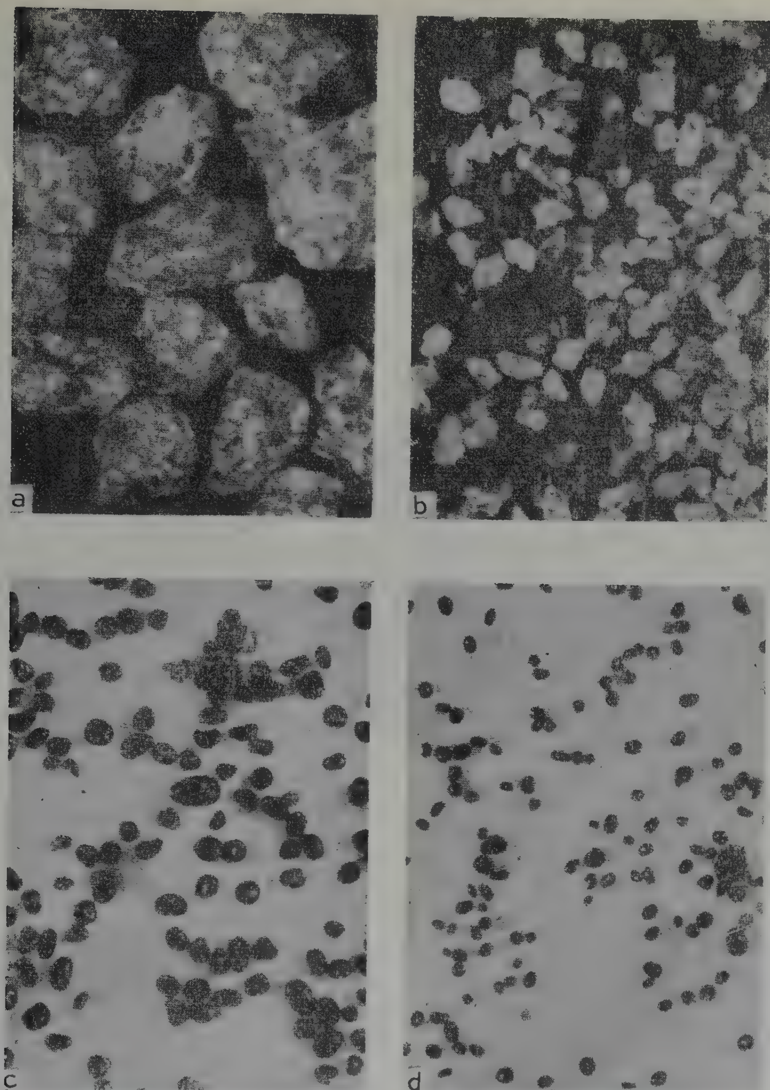


FIGURE 5. Grains of quartzitic glauconitic siltstone

a - fraction 0.25 to 0.5 mm, before the irradiation; b - components disintegrated in ultrasonic processing; grains < 0.1 mm obtained from 0.25 to 0.5 mm fraction; c - isolated with an electromagnetic separator; d - irradiated for additional 30 minutes.

to the competing processes of dispersion and agglomeration. It is of interest that the maximum dispersion is achieved at the same frequency for suspensions of different granulometric composition obtained from the same kaolinite, but one with an added stabilizer (ammonia) and the other without it. A count of the average-size particles under the electron microscope has shown that the best dispersion of a kaolinite suspension is obtained at ultrasonis frequencies of 960 kilocycles, with 320 kilocycles for montmorillonite suspension.

M. Crowley and A. Walch have demonstrated that the most complete disintegration of kaolinite suspension is achieved after a 5 to 15 minute irradiation. The Germany scientists have obtained similar optimum paramenters for kaolinite (960 to 1000 kilocycles; 5 to 10 minutes; the suspension concentration, 1 to 2.5%). Ultrasonic dispersion os kaolinite suspension has found a wide application in research and factory practice on local ceramic (kaolinite) raw material.

H. Keller, A. Koch, and K. Tasser [12]

have developed an original method of applying mineral suspensions to preparates, in electron-microscopic studies. A few drops of suspension, at the bottom of a glass cylinder, are processed with ultrasons until a "fog" appears in the upper part of the cylinder, as a result of the suspension "vaporization" [8]. This fog cloud is an aerosol whose every drop (1 to 2 μ in size) contains a particle of suspended material. After the generator has been cut off, the fog particle settle directly on the collodion film of the electron-microscopic preparate. This method precludes the formation of agglomerates. Electron-microscope photographs in Figure 6 illustrate this method.

(Figure 7-b). In the third sample, irradiated for 5 minutes, the bands in addition to splitting, were broken up into extremely fine irregular scales (Figure 7-c). Control electron-microscopic photographs of the same glauconite suspension but dispersed by a mechanical method, show irregular, commonly clustered aggregates This is the way glauconite has been illustrated in many works citing electron-microscopic photographs of its suspensions.

As of now, there have been no systematic experiments dispersing glauconite at higher frequencies.

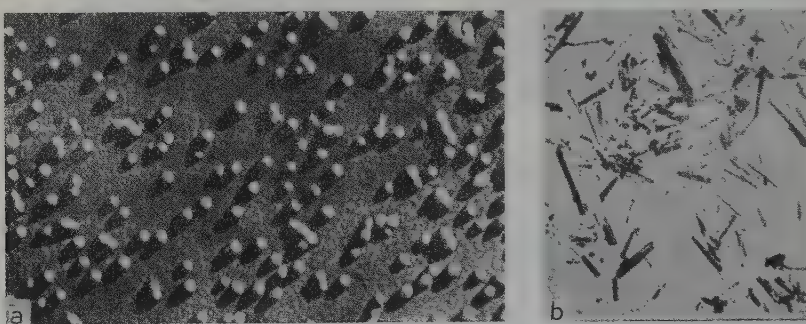


FIGURE 6. Electron-microscopic photographs of finely dispersed powder of polyvinyl acetate and microasbestos in an ultrasonic fog chamber.

a - natural size; b - 24,000 X.

b) Experimental Results

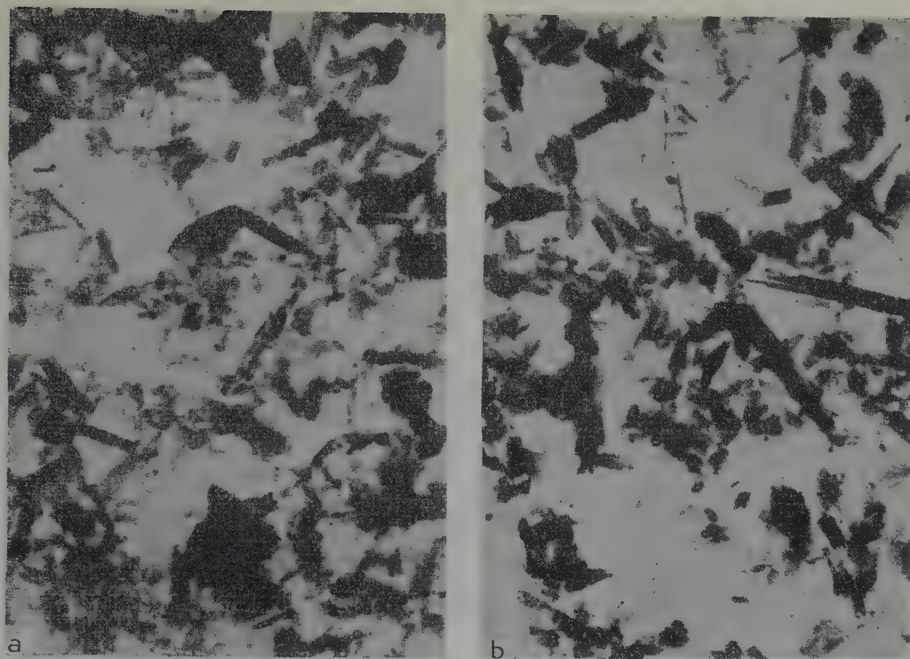
The purpose of our own experiments was merely to effect the dispersion of various mineral suspensions in order to obtain demonstrative electron-microscopic photographs.

Experiment 1. Dispersion of glauconite aggregate grains. Pure collomorphic grains of deep-green glauconite were picked out of the Riphean quartzitic siltstone, from the Serdobsk control test (depth, 2 m; sample 32/56). The first sample was irradiated for 5 minutes (frequency, 22 kilocycles; intensity, 3 wt/cm^2; suspension concentration, 1%). Studied under the electron-microscope, this suspension revealed an even distribution of more or less uniformly elongated tabular scales. A number of the tablets showed distinct vertical faces, giving them a pseudo-hexagonal aspect (along 001), with well-expressed faces of the second order pinacoid (010) and two pairs of prism faces (110) (Figure 7-a).

The second sample was irradiated for 10 minutes, under the same conditions. Here, the tablets were seen to split up along cleavage planes (010), into thin ribbon-like bands

Experiment 2. Dispersion of dickite aggregates. Dickite appregates were elutriated out of the cement of a quartzitic sandstone where they, occurred among individual quartz grains in central parts of former porous segments. This rock belongs to Riphean deposits penetrated at 26 m by the Serdobsk control test hole (sample 4/56); the irradiation time, 1.5 minutes; frequency, 22 kilocycles; intensity, $\sim$ 3 wt/cm^2; concentration, 1%. Electron-microscopic photographs of preparates of the irradiated suspension reflected its definitely heterogeneous nature. Present along with coarse pseudohexagonal tablets, of up to 5 and 10 μ, were small and well-shaped crystals of the same habit, up to a few tenths of a micron (Figure 8-a). Repeated experiments with irradiation periods of 5 and 10 minutes have led to a sharp reduction in the scale size; the overall heterogeneity of the preparation was preserved, although not to the same extent as before.

For control, electron-microscopic photographs of the natural shear in a porous segment of the sandstone were taken in the Electron-Microscopic Laboratory of the I. G. E. M., by the coal method with platinum shading. A study of many such photographs reveals the same typical



lack of uniformity in the dimensions of indivisible dickite particles observed in the first suspension, after its 1.5 minute processing with ultrasons. Present along with relatively large crystals (up to 10 μ) in volume photographs of the natural shear plane are abundant pseudohexagonal tablets a few tenths of a micron large (Figure 8-b). Obviously the coincidence in the aspect and size of dickite indivisibles, in the first suspension and in photographs of the natural shear plane, is not accidental; a brief

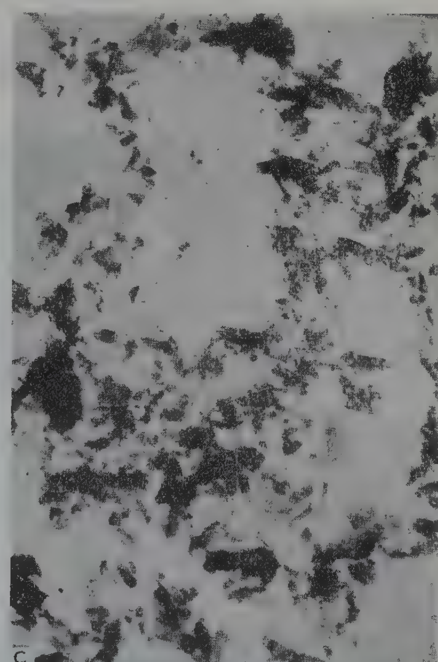


FIGURE 7. Electron-microscopic photograph of glauconite grains

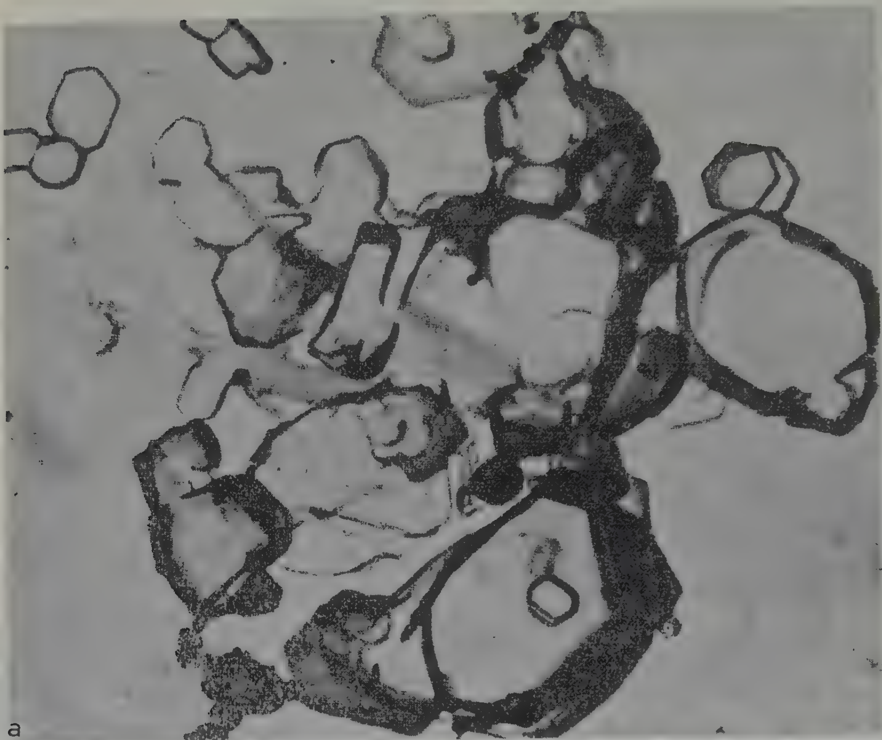
a - suspension preliminarily irradiated by ultrasons, for 5 minutes, 5400 X; b - same for 10 minutes, 5400 X; c - same for 15 minutes, 5400 X.

ultrasonic processing of the suspension appears to cause only a natural disintegration of aggregates into their indivisible component particles, without any appreciable damage to the particles.

5. Ultrasonic Scouring of Various Components

a) Published Data

Ultrasonic scouring of intricate details shaped out of various materials (metal, glass, etc.), to remove films of oxides, fats, polishing paste, minute abrasive particles, etc. has been widely used in industry and has come to be regarded as the most effective cleaning method [3]. As a rule, low frequencies (~ 25 kilocycles) are used in scouring large and rough surfaces; high frequencies are used for delicate minute details, and particularly for small and precision apertures (a desirable ratio is $\lambda < d$,


a


b

here λ is the wave length and d is the aperture iameter).

W. Wetzel used ultrasons in processing orroded surfaces of clastic minerals in a elitomorphic groundmass of soil. Also isoated in this process were pure authigenic conretionary formations. Small amounts of soil 2 to 3 gm) were exposed to ultrasons for 1 to minutes (frequency 800 kilocycles), then insed, sorted out and studied with a binocular icroscope.

b) Experimental results

We used ultrasonic scouring only in obtaining clean" glauconite grains free of spots and icrogrowths of other minerals. After a disntegration of the original rock, the glauconite rains separated with an electromagnet were rocessed ultrasonically for 5 to 30 minutes requency, 22 kilocycles; intensity, ~ 3 t/cm2), (Figure 5-c, d) which resulted in a niform "peeling" of peripheral parts of the rains. The ferruginous "jacket" on quartz and eldspar grains was removed in the same way. xperiments were made on cleaning and procssing the surface of shells removed from rerystallized limestone.

on solid particles are more effective in an ultrasonic field than in mechanical action; the hydraulic shocks split up the microfractures, pores, cleavage planes, etc., which is not possible in mechanical action.

Of interest in this connection is an experimental phenomenon observed in individual thick sections irradiated in our and other laboratories. The hydraulic shocks take place at each vibration period. At frequencies of ~ 22 kilocycles, about 10^5 shocks occur during a usual observation period (about one minute). The size of cavities in the solid surface are on the order of 0.1 to 1 mm or even smaller. On the average, ~ 10^{-5} mm^3 or less material will be removed from the particle's surface, by each shock. If the distribution of these shocks over the solid surface plane were quite haphazard, we would have obtained a more or less uniformly dull surface, after approximately 10^5 shocks. As a matter of fact, a longer irradiation always results in an irregular and haphazard enlargement and deepening of a comparatively few cavities in the solid surface. This indicates that the localization of cavitation centers depends on microtesture of the solid surface. This circumstance appears to be of no importance in the dispersion of homogenous media, in many branches of industry; it may be

FIGURE 8. Electron-microscopic photograph of dickite grains

a - suspension of dickite aggregates preliminarily irradiated by ultrasons for 1.5 minutes, 14,000 X, Laboratory I.G.E.M., G.S. Gritsenko; b - electron-microscopic photograph of a natural shear-plane in a porous segment of sandstone, 16,000 X, same laboratory.

6. Discussion of the Results

1. Ultrasonic methods of dispersion and isintegration are basically different from the onventional mechanical methods. Indeed, hen the operation is performed in a mortar r by any other mechanical means, a blow on ne object processed may affect any part of it nd the force of the blow may operate in any irection. In well-stratified bodies, the preominant direction of these shocks may happen o be normal to cleavage planes. In a low freuency ultrasonic field (~ 25 kilocycles), ydraulic shocks of cavitation will tend to be onfined to those points on the surface of solid odies where there are conditions favorable or them, such as depressions, microfracures, cleavage, etc. Because of the small estructive radii of hydraulic shocks, their irection is normal to the surface where the avitation bubbles are destroyed. Accordingly, vith respect to dispersion into original crystals, s well as to disintegration into structural comonents and to scouring the surfaces with nicroscopic details, the points and direction f application of hydraulic cavitation shocks of importance in the dispersion, disintegration, and scouring of mineral objects where it is desirable to preserve the structural components. Our plan of systematic studies includes appropriate experiments in this field.

2. Experiments of A. Mathieu-Sicaud and G. Levavasser have shown that a maximum kaolinite dispersion takes place at ~ 960 kilocycles; montmorillonite, at ~ 320 kilocycles; and barium sulfate, at 960 to 1600 kilocycles. There should be no mechanical resonance phenomena on individual particles, because their size is much smaller than the wave length (about one mm). It is probable that from this frequency on, the agglomeration effect is stronger than that of dispersion. However, we are at a loss, at the present time, as to exactly what physical processes are responsible for this phenomenon.

Equally incomprehensible are the results of experiments by M. Crowley and A. Walch, as well as of other students, who have demonstrated the presence of an optimum irradiation time (about 5 to 10 minutes) for kaolinite clays,

after which their dispersion begins to deteriorate, giving place to agglomeration. It is possible that these phenomena are caused by a rise in the surface energy of individual particles in the course of their irradiation by ultrasons.

3. A correlation of our own initial positive experimental results in the disintegration of homogenous media (kaolinite and dickite) into primary particles by means of low frequency ultrasons, with those obtained by foreign scientists who have demonstrated the existence of optimum dispersion frequencies for a number of media, shows that there is no cleancut answer as to what dispersion regimen (frequency, intensity, duration) is the most effective in electron-microscopic and granulometric studies of homogeneous bodies. It appears that both high and low frequencies can be used for that purpose, with a proper combination of the intensity and duration of ultrasonic irradiation to be determined for each sample under study.

It should be emphasized that the task of disintegrating a homogenous medium into structural components is different in principle from that of obtaining the finest dispersed medium. The two tasks may be accomplished by ultrasons but the method of this accomplishment appears to be different in each case.

4. Experiments in disintegrating heterogenous rocks into structural components have shown that maximum disintegration takes place at low frequencies (Experiment 1) and that the intensity of disintegration rises with that of the ultrasons (Experiment 2). The disintegration process is determined by cavitation. The number of fractures and pores showing at the surface of a particle is proportional to the square of its dimension; its mass is proportional to the cube of the dimension. It is natural, therefore, that the disintegration capacity, determined by the relative weight of fractions disintegrated, should be the highest with the smallest fraction, 0.1 to 0.25 mm (Experiment 3). Obviously, the maximum rock disintegration in the first 5 minutes (Experiment 4) is due to the "working-out" of all microfractures left in rock grains after the mechanical crushing. The repeated irradiations work on "smoother" grains which have lost some of their larger fractures.

It should be noted in connection with experiments 1 through 4 that the relative weight of particles passed through the 0.1 mm mesh sieve is a criterion of both the disintegrating and dispersing capacities of the rocks, the two processes proceeding simultaneously. Further study should deal with the cavitation dispersion of many pure minerals of various origins.

SUMMARY

1. Ultrasons can and should be used as an auxiliary means of processing the rock and mineral samples in specialized mineralogic studies.

2. Low frequency ultrasons can be successfully used in dispersing clay suspension, in electron-microscopic studies, and in scouring the minerals and other structural rock components. The mechanism of this operation is determined on the whole by cavitation. The optimum duration of an ultrasonic action with the given ultrasonic intensity is determined experimentally, depending on the nature of the study subject and the purpose of its processing.

3. Ultrasonic disintegration of consolidated rocks into their component minerals is related to the cavitation phenomena and is realized most effectively with low frequency ultrasons. This process is inadequately known and warrants additional study.

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REVIEWS AND DISCUSSIONS

THE STRUCTURE OF THE NORTHERN TERMINAL OF THE ARCTIC URALS[1, 2]

by

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The two works by M. Ye. Raaban published in a single volume represent the results of her field work in two areas of the northern part of the Urals. This area is still comparatively little known. A complete description of these regions difficult to access, with a complex distribution of facies in thick and almost barren Paleozoic sections with extremely intricate tectonics, will take generations of geologists. Naturally, each new publication on this area is of lively interest, especially where M. Ye. Raaben does not confine herself to mere descriptions but attempts explanations and broad generalizations.

We believe it expedient to discuss certain controversial points and those assertions contrary to our own observations.

1. The author states in the first work (pp. 25, 27) that the Obeiz (Telpos) Lower Ordovician formation wraps around the Ray-Iz massif, in the north and northwest, and that "the last outcrops of these quartzites can be seen in Mt. Shlem." As a matter of fact, this formation is not exposed south of the course of the Upper Sob; and the quartzite blocks on Mt. Shlem are not Obeiz but belong rather to a motley tuffaceous formation underlying the Lemva Ordovician phyllite in the Yelets River area [2].

2. Another statement (pp. 24, 57, and 95), supported by references to M. S. Kaletskaya and A. D. Miklukho-Maklay ([7], pp. 24-25) has it that there is a transition from the Obeiz to the phyllite formation in the Pad-Yaga-Musyur Ridge area. We believe this position extremely controversial; the peculiar uneven-grained quartzitic rocks of the Nad-Yaga-Musyur appear to be rather older than Ordovician; the presence of red slates, here, is not an argument for a transition to the phyllite formation, inasmuch as the phyllite is almost free of red slate, in the adjacent Sob trough.

3. We cannot agree with the statement (p. 24) that there is a break and an abrupt change in the degree of metamorphism at the base of the phyllite formation (in the northern part of the Lemva zone). According to our data, it rests here without a break on the tuffaceous formation mentioned above; nor is there an appreciable difference in the degree of metamorphism. Furthermore, according to our data, the phyllite formation does not rest on amphibolite anywhere in this vicinity.

4. "Dark-green sandstones" with "feldspar grains", from the Kacha-Myl'k formation along Lemva River are described in the second work (p. 56). According to our data, motley hornblende diorite which forms a small intrusive body is exposed here.

5. Also doubtful is the reference to "pebbles of green metamorphic schist" in shale of the same formation. I have not seen any such pebbles in that exposure; it is odd that they should be present in shale.

6. We regard as erroneous the statement of M. Ye. Raaben (pp. 65, 69, 87), about terrigenous rocks in Silurian dolomite, along the upper Lemva course, in the east limb of the Malda anticline. In our careful study of these deposits, we have observed nothing but dolomite. Perhaps there is some error in definition or a mixup in samples. This is an important point because, contrary to M. Ye. Raaben's statement, we have the impression that there is no transition between the Tisva-Iz and Yelets Paleozoic complexes, and no convergence along their tectonic contact.

7. The author notwithstanding, there is no

[1] K voprosu o stroyenii severnoy okonechnosti Pripolyarnogo Urala.

[2] Observations on M. Ye. Raaben's "Stratigraphy of Ancient Formations in the Arctic Urals. Stratigraphy and Structure of the North Terminal of the Arctic Urals". Trudy Geol. Inst. Academy of Sciences U.S.S.R., 35, 1959.

transition to carbonate facies of the Yelets zone, in the Kharota formation of the Niya-Yun trough.

8. In describing the Devonian from the Lemva zone, M. Ye. Raaben omits the Paga formation, most likely Devonian and in some respects quite similar to the Tisva-Iz Devonian rocks. Also omitted for some reason is the Yelets Devonian carbonate section, where all three divisions of the Devonian are present and characteristically fossiliferous.

9. There are a number of vexing errors in the description of the Lek-Yelets formation (Devonian) in the Lemva zone (pp. 110-111). This formation is developed only in the north, in the Yelets and Sart-Yu basins, and does not accompany the Kharota formation throughout the rest of the Lemva zone, as stated on p. 110. More specifically, it is not exposed along the Kharota River; there are instead black shales, Silurian and Carboniferous. This fact invalidates M. Ye. Raaben's observations on facies changes in that formation (p. 111).

Contrary to what M. Ye. Raaben says, there are no sandstones in the Lek-Yelets formation; she mistook for sandstones the beds of tough limestone which form a rusty-brown ferruginous crust. Significantly the author herself mentions the presence of crinoid segments in that crust.

Despite the M. Ye. Raaben statement on p. 112, I have never assigned the Lek-Yelets formation to the Lower Devonian. I have mentioned on many occasions that this formation largely carried a Middle Devonian fauna, although it may embrace all of the Devonian [1, 3, 4].

10. Relations of the various Devonian formations and facies in the upper Lemva course and along its tributary Bol'shaya Nadota (or Naduta) are quite complex and far from being clear. We take issue with a number of M. Ye. Raaben's statements on that region. First of all, the Tisva-Iz-type deposits along the Lemva, above the Vostochnaya Taborta mouth, do not form lenses in Lower Devonian limestones and dolomites, as described on pp. 70-71. Neither are they bound by the Lower Devonian in the east; the Karpinskia gigantea Khod. limestones do not constitute an eastern fringe of a Tisva-Iz "lens" but rather are part of a peculiar local interval, apparently a facies of the Tisva-Iz series, most likely separated by a western fault from Koblentz-Eiffel limestones and dolomites. In the east, this motley sequence contacts the Mt. Tisva-Iz quartzite.

11. The Nadota formation is Lower Eiffelian, according to M. Ye. Raaben; and of a much wider age range, according to our data. Thus a coral similar to Kophophyllum, an exclusively Silurian genus, has been collected from it in the middle course of the Matya-Shor Creek; and Neostringophyllum waltheri Joh. (Upper Givetian) and Cyrtospirifer ieremejevi Tschern. (Frasnian), in exposures at the foot of Mt. Olysya (identification by Ye. D. Sotkina and V. V. Bogachev). The lower interval of the Matya-Shor formation, as designated by M. Ye. Raaben, is a facies of the same Nadota formation; according to our data, the age of its marly limestone and shale ranges from the uppermost Eiffelian and apparently to the Frasnian.

12. The Tisva-Iz formation is more properly called a series or sequence [2, 4], because its age ranges over three geologic periods; as a single homogeneous interval it is unlike the Yelets and Lemva sequences. It is possible that in the future it may be divided into formations.

I must say that my statement on the presence of a Silurian fauna in this sequence [2, 4], a statement referred to by M. Ye. Raaben (p. 80), is wrong. The corresponding trilobites (as identified by Ye. A. Balashova) are Devonian. It also seems to be advisable to support by a more complete collection the Ordovician age of the fossils collected by A. V. Khabakov, in 1947.

There arises the complex problem of the relationship between the Tisva-Iz series and the Nadota formation. As we have seen, the Nadota formation may embrace a range from the Silurian to the top of the Devonian. Lithologically, it is identical in all details with the Tisva-Iz series (M. Ye. Raaben notes in two instances (pp. 73, 123) that it is "indistinguishable from the Tisva-Iz formation"). Is it possible that the Nadota formation may be a member of the Tisva-Iz series?

13. We must take issue with the statement that "the Tisva-Iz shales are overlain conformably" by Carboniferous deposits of the Lemva type (the Vorga-Shor formation; pp. 80-81, 112, 121, 129). M. Ye. Raaben herself does not seem to be quite sure of that; in another place (p. 81) she states that, generally speaking, "an overthrust of Carboniferous deposits... is little probable." In 1952, we made a special effort to look up that contact and we are convinced that it is tectonic.

14. We cannot agree with M. Ye. Raaben (p. 48) that for "most Ordovician, Silurian, and Devonian horizons," the transition from Elets carbonate facies to Lemva facies "is accomplished by way of the intermediate Iz sequence." According to our observations [2, 4], the only transition is from the Lemva Silurian to the Tisva-Iz facies; by stretching a point here and there, a certain similarity can be assumed for Devonian facies; however, there is no evidence of an Ordovician transition. On the other hand, we see no evidence of any transition from the Tisva-Iz to western carbonate facies and we

take issue with all arguments presented by M. Ye. Raaben on that subject. Thus, we fail to see any lenses or lentils of Tisva-Iz type rocks, at the eastern margin of the carbonate complex. Very much open to argument is M. Ye. Raaben's statement on the concentration of carbonate lenses in the Tisva-Iz section, near its western boundary (p. 80); see, for instance, the abundance of limestone east of Mt. Tisva-Iz, along the Parnok River. As we see it, these two complexes are in tectonic contact.

15. It is asserted in two places (pp. 82-83) that the Permian section along Lemva River "is irregularly cross-stratified, in its entirety." We have observed only occasional cross-bedding.

16. A thrust which M. Ye. Raaben calls the Khoyba is described in detail on p. 125. This description contains a number of misrepresentations: 1) the interval thrust over the Kechpel formation is most likely Silurian rather than Ordovician; 2) the thrust passes through the creek mouth, rather than being exposed; the visible thrust, mentioned by M. Ye. Raaben, is a supplementary feature within the overthrust Kharota formation; 3) this invalidates all deliberations on the trend of the thrust line: local relief is not strong enough to explain the steep arch of the thrust line in the Lemva Valley, by the 25° dip of the fault surface; its true dip is probably flatter, and in addition it undoubtedly is bent in plan.

17. M. Ye. Raaben believes that the large synclinal and anticlinal structures of the Kozhima zone "continue" within the Tisva-Iz complex; she concludes that the latter is autochthonous (p. 124). We cannot agree with that. The author herself states correctly (p. 120) that the Kozhima structures "are not at all discernible from elements of the Tisva-Iz formation," because, and this is our own observation, the latter dips almost everywhere to the southeast.

The apparent conformity of shale and carbonate horizons, observable here and there at the very contact between the two sequences, may be explained by the shale section being adapted to the form of its bedding slip surface. I believe it more probable that the entire Tisva-Iz shale section has been thrust over the carbonates, from the east.

The area of the Arctic Urals northern terminus is of great interest as the site of a hard junction of three facially different Paleozoic complexes; the Yeletsk carbonate facies, Tisva-Iz quartzitic facies, and the predominately argillaceous Lemva facies. M. Ye. Raaben presents her interpretation of the structrue of that and of some of the areas to the north, and attempts to explain the hard junction of facies in this and certain other Uralian regions.

The author regards the Lemva zone as depressed with relation to the Kozhima and Yelets areas, apparently because the Precambrian is not exposed here (pp. 47-48). This position can be argued; the Lemva zone may be regarded positive, just as well, because the Ordovician and Silurian are developed at the entrance to it from its fringe of "uplifted" areas (in the north and in the south), at those places where vast expanses of the Permian should have been, at periclinal closures of major anticlines plunging toward that zone.

M. Ye. Raaben correlates the Lemva and Tisva-Iz facies, detects gradual transitions between the Tisva-Iz and the carbonate facies, and finally concludes that "the Lemva structural facies complex is autochthonous rather than allochthonous" (p. 48).

I cannot go along with that. Despite the slight convergence of facies mentioned above, I do not see how the Tisva-Iz and Lemva series can be regarded as a single series; more specifically, I reject the normal occurrence of the Carboniferous Vorga-Shor formation on Tisva-Iz shale. I also reject the presence of lenses and other alleged evidence of a transition from the Tisva-Iz to Yelets (carbonate) facies and I believe that they are separated by a fault. The thrust of the Lemva formation over the Yelets, conspicuous in the Malaya Nadota area, I believe to be a considerable and flat one, because of 1) an abrupt change in facies, from the Ordovician through Permian; 2) the bizarre bend of the thrust line which cuts across the trend of thick folded structures; 3) a regional development of the Ordovician over many tens of kilometers, in the southern half of the Lemva zone, in the area of the periclinal closure of a number of large Kozhima anticlines where the Permian should have been developed; 4) the presence of an autoclastic "massif" (cyclopic breccia), at the contact, tens to hundreds of meters thick in its exposures along the Malaya Nadota; this "mess" is strikingly similar to the Precambrian Mohnian formation described and illustrated by E. Greely from the island of Anglesey [8], and to a tectonic pseudoconglomerate described from Scotland by B. Peach and J. Horne [9]; 5) the rolling-out and brecciation effects in the Lemva area, at the thrust contact of the Permian and the Ordovician phyllite formations, over a distance of at least 0.5 km, on either side of the tectonic contact (not observed anywhere else, in either formation, despite the intensive general isoclinal folding).

Assuming that the Lemva facies are "near-axial" (p. 112), the Ordovician phyllite would have to be pushed west over a distance definitely over 10 km, in order to arrive at the west slope points remote from the "axis", such as the headwaters of the Malaya Nadota and the middle Lemva course. In other words, the Lemva sequence is not in situ; i. e., it is

allochthonous (unfortunately, it is so called by M. Ye. Raaben only in an obvious erratum, on the last page of her work).

M. Ye. Raaben develops a concept of "continually rising" (cosedimentary?) anticlinal structures which served as barriers to terrigenous deposits and as a factor in the hard junction of terrigenous and carbonate facies (e. g., the Malda anticline). Unfortunately, the author fails to demonstrate the presence of an uplift in the ancient relief, on the site of the present Malda anticline, "during the deposition of the Tisva-Iz formation." She writes, "This is suggested... by the definite association of the narrow band of facies changes and the crestal part of the anticline" (p. 88). Her map (p. 51) shows, however, that the facies junction does not at all follow the anticlinal axis but rather crosses a number of synclinal and anticlinal axes. The breccia-like rocks, which M. Ye. Raaben is inclined to consider as having originated in submarine slumps, we regard as the products of secondary dolomitization. Nor am I inclined to regard the motley Balban-Yu dolomite as a reef formation. Finally, granting that M. Ye. Raaben is right as to the origin of these rocks, their position in the limbs of the Malda anticline is not a proof of a long uplift contemporaneous with deposition; they probably were developed in the crestal part, as well, and have been eroded. Thus, the barrier theory of M. Ye. Raaben is purely speculative.

In my own time, I was confronted with this problem of hard facies junctions [5, 6]. I attempted to demonstrate that such features do not necessarily call for particularly large horizontal displacements. Still, I have no doubts as to the presence of a number of considerable thrusts in that area.

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CHRONICLE

PROBLEMS IN THE GEOLOGY OF ORE DEPOSITS AT THE TWENTY-FIRST SESSION OF THE INTERNATIONAL GEOLOGICAL CONGRESS[1]

by

V.I. Smirnov

Various aspects of the geology of ore deposits were considered in three sections of the Twenty-First Session: 1) in meetings of Section 16, Genetic Problems of Mineralization; 2) Section 15, Genetic Problems of Uranium and Thorium Deposits; 3) in meetings of the subcommissions on the Metallogenic Map of World. The major problems of endogenetic and exogenetic mineralization, reflecting the present status of knowledge and the prevailing trends were discussed along with local and specific topics. However, the limited working time of the Session and its subcommissions and sections, four afternoons for Section 16 and three incomplete days for Section 15, precluded a thorough discussion of certain urgent problems of ore genesis.

Five problems were discussed in Section 16: 1) relation of mineralization and igneous activity; 2) genesis of ore deposits in sedimentary rocks; 3) zonation of ore bodies; 4) physicochemical factors of mineralization; and 5) origin of bauxite.

The section opened with the first problem and a paper by L. N. Ovchinnikov "Vertain Problems of Magmatic Mineralization". The speaker presented his experimental concepts of magma as an ionic liquid with dispersed metallogenic elements in ionic and atomic states; i. e., the behavior of these elements and their capacity for separation and escape beyond the melt are determined by the mode of their occurrence.

O. Oelsner (G. D. R.) discussed the alteration of exhalation-sedimentary type deposits in connection with an intrusion of basalt magma, during the initial igneous period, into poorly diagenetized sediments in subsided parts of geosynclines. A basalt magma, as shown by the speaker's calculations, can assimilate lateral rocks up to 32% of its volume, to form gabbro rocks. The simultaneously liberated residual ore solutions, in their upward movement, may not reach the sea bottom, but instead form ore deposits directly in the plastic rocks.

E. Tautzsch (G. D. R.) concluded on the basis of his study of the complex body of volcanic and subvolcanic rocks of central Germany and the associated nonferrous mineral deposits that their mineralization had coincided with the eruptive activity of residual magmatic centers located at various depths in the sial, in the transition period from synorogenic to subsequent igneous activity.

The paper by V. Hanuš (Czechoslovakia) dealt with metasomatism in mineralization, dependent on the ratio of the degree of saturation of a hydrothermal solution in rock components passing into solution, to the incoming mineralizing compounds. His compatriot M. Štemprok reported on the stages of postmagmatic metasomatism in the formation of Tsinovets (Tsinwald) tin deposits in the Erzbegirge.

W. Garter (U. S.) demonstrated that the Cabildo (Chile) stratified copper deposits, similar in mineral paragenesis to vein-type deposits, are genetically related to a diorite intrusion.

R. Carpenter (U. S.) stressed the fact that both the hydrothermal alteration of lateral rocks and the molybdenum mineralization at Cuesta (New Mexico) has been determined by Tertiarty granite-porphyry and rhyolite-porphyry intrusions.

T. Gjesvik's (Norway) paper on the possible mode of origin of pyrite ore deposits in Skorovess, Norway, belongs more properly to the next problem.

[1]Problemy geologii rudnykh mestorozhdeniy na XXI sessii Mezhdunarodnogo geologicheskogo kongressa.

A lively discussion was provoked on the sub-ct of the origin of stratified ore deposits in edimentary rocks. The point of discussion as sharpened by the fact that a number of peakers advocated a sedimentary origin for any deposits formerly believed to be hydro-hermal. N. Fisher (Australia) included the amous Mt. Isa deposit, in Australia in the edimentary group; the same origin was as-gned by H. Michel and G. Scolari (Republic Congo) to the Passa Velli polymetallic de-osit, in the Congo, and to the ostensibly sim-ar Salafossa deposit, in the Alps, by D. olbertaldo and G. Franceschetti (Italy); and to ispersed lead-copper ores in Carboniferous-ermean dolomites of the western Himalayas, y Roy Chowdhary, M. Subramanian, and P. anerjee (India).

The concensus is that the weight of opinion as shifted considerably in favor of a syn-enetic origin of stratified ore deposits, com-ared to several years ago when this concept as vigorously opposed by the magmatists. owever, there is a new slant in the sedimen-ary point of view. Its advocates are inclined o explain the presence of enriched segments in number of these deposits, more specifically hose local vein-contact accumulations control-ed by cross-faults, by a subsequent action of ostmagmatic processes and the associated re-istribution of mineralizing material. In pro-inces of deeply metamorphosed Precambrian nd lower Paleozoic sequences, this redistri-ution of mineralizing material is ascribed to hermal solutions originating in the process of alongenesis (E. Grip, Sweden). Thus, the trata with dispersed sedimentary mineraliza-on are regarded as a natural arsenal for hy-rothermal mineralization. In this connection, articular importance is attached to black bi-uminous shales with a high metallic content V. Marmo, Finland). A weak point of this heory, virtually not touched upon, is the physi-al chemistry of the redeposition of minerali-ing material in its regeneration from sedi-nentary to postmagmatic products.

The author of this communication spoke on he types of hypogene zonation in hydrothermal re bodies: zonation by stages and by facies, vith three varieties for each type. Interesting lata on columnar zonation in ore veins of the risco (Mexico) polymetallic deposit were ommunicated by G. Koch and R. Link (U. S.); nd on vertical zonation of additive elements in he Centine (France) lead-zinc deposit, by C. evy and J. Prouhet.

Strictly speaking, physicochemical and hermodynamic conditions of mineralization vere not considered at the Congress. Among hose listed in this category, the paper by J. Gill (Canada) dealt with experiments on diffu-sion of copper sulfides in a solid phase, at about 400°C; while E. Roedder (U. S.) spoke on iquid inclusions in ore-forming minerals.

In comparing bauxite deposits in Europe and North America, V. Allen (U. S.) came to the conclusion that ground water is of great im-portance in their formation. H. Hose (Canada) classified bauxite deposits by the composition of their underlying rocks.

The score or so papers read in the Section on "Genetic Problems of Uranium and Thorium Deposits" contained much new material on the geology, mineralogy, and geochemistry of uranium deposits and on radiometric methods for their exploration in the U. S., Union of South Africa, Sweden, Spain, Yugoslavia, France, and Chile. Our attention was engaged by four of these papers.

First of all, the paper by the Japanese geo-logist N. Katayama, on the origin of uranium deposits in sedimentary rocks, was definitely interesting. He differentiates the following types:

1. Syngenetic deposits.

2. Deposits formed by ground water (in-filtrational), subdivided into 2a — basal con-glomerate type; 2b — ore lenses and "loaves" in sandstone; and 2c — "water-table" type with enriched zones directly below the present or earlier water table.

3. Crystallized deposits in Archean con-glomerate.

The author assigns all of the more or less substantial sedimentary uranium deposits to the infiltrational type, thus underscoring the great significance of ground water in the formation of commercial ore deposits of this metal. He boldly but fairly reasonably assigns the Wit-watersrand (South Africa) and Blend River (Canada) type deposits to ancient infiltration formations, preserved despite subsequent re-gional metamorphism. In so doing, he suc-ceeded in adding a new and original concept to the fairly extensive and seemingly exhaustive list of hypotheses on the origin of uranium in Precambrian conglomerate.

Considerable argument on the origin of uranium in ores was provoked by L. Page's (U. S.) paper. While not denying the possi-bility of leaching, redistribution, and secondary deposition of this metal by ground water, the author ascribes paramount importance to primary deep-seated sources of uranium min-eralization. He strives to demonstrate that, in most ore areas, the ore-bearing centers were located in deeper reaches of acid intrusions, with the uranium leached out of them at later stages of fractional crystallization, during the intrusion of diabase and lamprophyre dikes.

In the published paper by E. Noble (U. S.), the accumulation of uranium in corresponding

belts of the Colorado Plateau is associated with a drop in the lateral pressure of uranium-carrier ground waters, in their flow through linear zones of fractured rocks, now rendered more permeable. In this connection, the author drew paleoisobars on the plateau surface whose margin determines the linearly extended position of the uranium deposit zone.

The paper by R. Ninger, D. Everhart, N. Adler, and J. Kratchman (U. S.) developed the idea of the substantial role of bacteria in sedimentary-uranium mineralization. Although these ideas were supported by a number of delegates, including P. Ramdohr, they are far from being well-substantiated, to judge from what has been said in meetings, and from published material.

This author, being busy elsewhere, was unable to attend the meetings of the subcommission on the Metallogenic Map of the World. Information on this subject was obtained from other delegates and from an inspection of maps exhibited with other geologic material.

The meetings of this subcommision were given to exchange of information on maps showing distribution of industrial minerals, compiled in various countries, and to inspection of these maps. Maps of ore deposits, coal, oil and gas, and ground-water resources, for British Borneo, Canada, Portugal, Northern Rhodesia, the U. S., France, and Japan were on exhibition. The Soviet Union was represented by a metallogenic map for iron, compiled under the direction of G. A. Sokolov. All these maps were of an index character, on a small scale: from 1:320, 000 (France) to 1:2, 500, 000 (iron ore deposits, U. S. S. R.).

Most of the foreign maps are rather primitive, divisible into three groups, on the basis of the method used in registering the mineral resources of a country. Group one is made up of standard recording maps on a topographic base (such as the map of mineral deposits of Northern Rhodesia). Similar maps on a geologic base belong to the second group. Among them are compound maps showing many kinds of industrial minerals, and simple maps for definite groups of mineral raw material. Examples of the latter are the U. S. Maps showing distribution of copper, lead, zinc, epigenetic deposits of uranium, thorium, rare earths, manganese, borates, asbestos, talc, pyrophyllite, and hyanite; also of the oil and gas fields of the United States. Points of occurrence of these minerals are plotted on individual transparent plastic sheets which can be laid over the geologic map of the U. S. These deposits are grouped by size and morphologic types; for example, copper deposits are differentiated into dispersed, replacement, vein, massive sulfide, and native types.

Constituting the third group are recording maps on a geologic base, showing prospective ore areas, such as the distribution maps of uranium, beryllium, molybdenum, and iron deposits of Canada. Drawn on waxed cloth superimposed on a geologic map of Canada, they show the points of occurrence of a mineral, classified according to magnitude and morphogenetic types, as well as areas with the known distribution of mineral raw material, and areas of probable or possible mineralization. The latter areas are outlined tentatively, by very careful extrapolation. Thus the mapping of industrial minerals, as represented at the Congress, was of no particular interest. It is not based on regional geologic regularities in the formation and distribution of mineral resources; in that respect, it is inferior to the methods of representing the spatial distribution of industrial minerals worked out in the Soviet Union.

During the field trips through Denmark, Finland, Iceland, Norway, and Sweden, the delegates had a chance to become acquainted in the field, not only with the geologic structure of those countries but with their commercial minerals as well. Soviet geologists visited and inspected a number of interesting ore deposits, among them the iron ore deposits of Swedish Lapland (Gellivara, Kiruna, Rektor), Central Sweden (ferruginous quartzite, skarn, etc.), ferruginous quartzite of Sudvaranger, and Arendal skarn ores of Norway; titanomagnetite and ilmenite ore deposits Talberg (Sweden), Christiansand and Ersunda (Norway); copper deposits Falun and Ammeberg (Sweden) and Stavanger Gront (Norway). We have seen lithium pegmatites of Varutresk (Sweden) and alkalic pegmatites at Langesunfjord (Norway); the Knaben molybdenum deposit and collections from the popular Kongeberg silver ore deposit in Norway. Our geologists had an opportunity to become acquainted with rare-element carbonatites of Sove, Norway, and with the unique series of carbonatite cone dikes of Alnö, Sweden.

Of particular interest was the visit to major chalcopyrite and polymetallic deposits in the Skellefteå area (Boliden, Alak, Kristenberg), discovered in the last 20 or 30 years under the thick drift mantle of northern Sweden. Being associated with a metasedimentary-volcanic spilite keratophyre sequence, they are among the oldest pyrite ores in the world. It is a great achievement of the geology department of the Boliden Company which develops these deposits, under the direction of the well-known Swedish geologist E. Grip, to have discovered over 20 major and rich deposits of lead and polymetallic ores underneath the drift mantle, in the tundra and swampy forests of northern Sweden. Their success was due to a comprehensive application of biochemical, hydrochemical, metallometric, and geophysical (aerial electromagnetometry and terrestrial) methods, with subsequent core drilling.

It can be stated without the fear of contradiction that the emphasis at the Twenty-First Session, in the field of the geology of ore deposits, was on the relationship between sedimentary accumulations of metals and subsequent alteration products by ground and hydrothermal water, and regional metamorphism. The other topics were only touched upon. Very little attention was given to such momentous problems in mineralization as the structures of ore field and deposits, and regional geologic regularities in the distribution of mineral formations. However, despite its somewhat one-sided treatment of geologic conditions determining the formation of ore deposits, the Twenty-First Session was important as a source of international scientific information and as an arena for exchanging opinions on new data and ideas on the origin of ore deposits.

THE TWELFTH GENERAL ASSEMBLY OF THE INTERNATIONAL VOLCANOLOGIC ASSOCIATION[2]

by

V. I. Vlodavets

The Twelfth General Assembly of the International Geodetic and Geophysical Union (I. G. G. U.) was held in Helsinki, Finland, July 26 to August 6, 1960. The I. G. G. U. comprises seven international associations, one of them being the International Volcanologic Association (I. V. A.), which also takes in the geochemists, to a certain extent.

The I. V. A. Assembly was attended by about 120 delegates, among them several outstanding volcanologists: A. Rittmann (Switzerland), H. Kuno and K. Yagi (Japan), J. Shirer and A. Richards (U. S.), L. Glangeaut, B. Géze and G. Notzline (France), L. Wager, S. I. Tokeev, and A. McGregor (Great Britain), J. Imbo and U. Ventriglia (Italy), M. Neuman van Padag (Netherlands), N. Fisher (Australia), G. Tadziyev and P. Edward (Belgium), H. Oftedahl (Norway), and others. The U. S. S. R. delegates were B. I. Vlodavets, G. S. Dzotsenidze, and S. I. Naboko. In addition, Ye. A. Lyubimova took part in the work of the I. V. A.

The geochemists were represented mostly by physicists and chemists, experts in the field of precision geochemical measurements: A. Nier, L. Aldrich, W. Brecker, S. Epstein, R. Clayton, and O. Tuttle (U. S.); R. Russell and R. Farquar (Canada); P. Eskola and T. Sahama (Finland); K. Korrens (F. G. R.); F. Hautermans (Switzerland); Sugavara (Japan); K. Burger (Union of South Africa); A. P. Vinogradov and A. I. Tugarinov (U. S. S. R.); and others.

A symposium on geochemistry was held on July 25, prior to the Assembly, with the volcanologists participating. Papers presented to the Assembly were read and discussed in symposia held during the meeting of the I. V. A.

The following papers were discussed in the section, Active Volcanoes: on the mechanism of ash and ignimbrite eruptions (A. Rittmann, Switzerland); agglomeratic flow of Bezymyannyy volcano, and secondary fumaroles in it (Bogoyavlenskaya, U. S. S. R.); the eruption of Puiejem volcano, Chile, during the catastrophic May-June 1960 earthquakes (G. Tadziyev, Belgium); terminology and classification of the Pelée and Katmai type eruptions (G. S. Gorshkov, U. S. S. R.); young submarine volcanoes near the Azores and their relation to tectonics (A. Mendosa Dias, Portugal); baked tuffs and allied pyroclastic formations in northeastern Japan (K. Yagi, Japan); a codification of protective measures for volcanic eruptions (B. Géze, France); and on volcanic activity of the moon (N. A. Kozyrev, U. S. S. R.).

Considered in the section on Volcanophysics were the origin of magma reservoirs and the role of volcanism in the thermal history of the earth (Ye. A. Lyubimova, U. S. S. R.); acoustic studies of active volcanoes (A. Richards, U. S.); geomagnetic anomalies in Italian volcanoes (I. Iokayama, Japan); feasibility of estimating the amount of juvenile water participating in volcanic explosions (Ye. K. Markhinin, U. S. S. R.); attempts at establishing a relationship or coincidence between eruptions of the Capelinchos volcano in the Azores and solar activity and terrestrial tides (A. Mendosa Dias, Portugal).

Presented in the section on Physical Chemistry of Magmas were papers on magma under geosynclinal and platform conditions (A. Rittman, Switzerland); water and basalt Magma (N. I. Khitrov, U. S. S. R.); equilibrium phases in systems belonging to crystallization processes in basalt magmas (J. Shirer, U. S.); transformation of nicheliferous olivine to nickel spinel at certain temperatures and pressures (A. E. Ringwood, Australia); distribution of Sr, Co, Ni, and Cr in basalt rocks (K. K. Turekian, U. S.); cause of divergent trends in the evolution of the lava composition of Malyy Semyachik and Karymsk volcanoes (V. I. Vlodavets, U. S. S. R.); water content, the degree of compaction and baking, and viscosity of native rhyolite glasses at different temperatures and pressures (R. A. Smith, I. Friedman, and W. Long, U. S.); properties of anhydrous (obsidian) and hydrous (retinite) acid volcanic rocks from modern French works (P. Bordet, France); action of molten magma on blocks of deep-seated rocks

[2]XII General'naya assambleya Mezhdunarodnoy assotsiatsii vulkanologii.

captured in a volcanic vent (L. R. Wager, Great Britain); crystallographic forms in diamonds from various kimberlite pipes (Ch. B. Slawson, U. S.); and differentiation and metasomatism in the plutonic-volcanic association of the ophiolite series in northern Greece (G. Brunnes, France).

The Paleovolcanology and Plutonism section hears papers on the distribution, composition, and the eruptive nature of British Tertiary lavas (S. I. Tomkeev, Great Britain); studies on the British Tertiary extrusive province (A. G. Mc-Gregor, Great Britain); Cenozoic basalt volcanoes in Queensland (J. G. Bast, Australia); the development of extrusive volcanism in Georgia in connection with its geotectonic history (G. S. Dzotsenidze and N. I. Skhirtladze, U. S. S. R.); processes of deep-seated assimilation and more recent metamorphism in the formation of Upper Cretaceous volcanics in southeastern Georgia (G. M. Zaridze and N. F. Tartishvili, U. S. S. R.); volcanic tuffs and tuffaceous lavas of Armenia (K. G. Shirinyan, U. S. S. R.); main stages in the tectonic and volcanic history of Kamchatka and urgent problems in paleovolcanologic studies (A. Ye. Svyatlovskiy, U. S. S. R.).

Papers read in the symposium on volcanic gases dealt with the chemical composition and radioactivity of volcanic gases from the Kilauea lava lake, from fumaroles and hot springs of Japan, and extracted from lavas by vacuum heating (I. Iwasaki, T. Ozava, M. Ioshida, T. Katsura, B. Iwasaki, and M. Kamada, Japan); the composition of volcanic gases and sublimates from Shovashidzan (Sh. Oana, Japan); the establishment of chemical equilibrium in volcanic gases from the Kilauea Lake, Hawaii (S. Matsuo, Japan); the extraction and analysis of gases occluded in the Nirangongo volcano lava (M. Chenier, R. Fabre, and G. Dadziyev, Belgium and France); Italian studies of the composition and distribution of volcanic volatiles (J. Imbo, Italy); the method of studying volcanic gases in Kamchatka (K. P. Florenskiy, U. S. S. R.); and on probable nonvolcanic (radon and perhaps argon) gases in fractures of the moon (J. Green, U. S.).

A number of papers treated the problems of hydrothermal processes related to volcanic activity: present hydrothermal processes (S. I. Naboko, U. S. S. R.); leaching of aluminum and iron by thermal waters associated with active volcanoes of the Kurile Ridge (K. K. Zelenov, U. S. S. R.); the composition of hydrothermal waters and the phenomena associated with mixing acid volcanic and marine waters, corroborating Zelenov's 1958 conclusions (L. G. M. Baas Beking, G. A. Taylor and W. Thomas, Australia).

Most of the papers in the symposium on The Relationship Between Volcanoes and Plutonic Bodies were presented by French delegates. L. Glangeaut (France), speaking on the origin of granite, the granitic crust, and volcanoes, asserted the possibility of rock solution with an accompanying metamorphism of granites originating in it; according to him there are five structural types in the earth's crust (three oceanic and two continental). As against that, H. Winkler (F. G. R.) believes, on the basis of his experimental and field work, that neither a differentiation of gabbro magma nor granitization in the solid state can explain the origin of granites and associated rocks.

The same problem was discussed by the French representatives: the relationship between granites and Precambrian acid volcanic and subvolcanic rocks in Central Sahara (M. Graveille); on eruptive plutonic and volcanic phenomena in Central Sahara (G. Remy); on the development of subvolcanic and volcanic processes in connection with Hercinian granite in the northern Vosges (G. P. Eyller); relations between assorted acid volcanic rocks and the corresponding plutonic rocks in the Maure and Esterel massif, southeastern France (P. Bordet); and the relations between volcanic and plutonic bodies in the area of Montagnes Noirs, Coss, and Lower Languedoq, in southern France (B. Géze). The best paper was illustrated with cross-sections from the area where the massif begins to where it changes to rhyolite dikes.

The formation of the subvolcanic and the entire Tezhsar complex in the Transcaucasus was described in a paper by G. P. Bagdasaryan (U. S. S. R.). G. D. Afanas'yev spoke on the relationship between Mesozoic-Cenozoic plutonism and volcanism in the Caucasus. Ye. K. Ustiyev's (U. S. S. R.) paper dealt with volcanic-plutonic facies in the Okhotsk belt and with problems in magnatism-transformism. H. Oftedahl (Norway) spoke on two comagmatic rocks, plutonic laurvikite; and volcanic rhombic porphyry, exposed in the Oslo area. M. N. P. Bott (Great Britain) reported on a negative gravity anomaly over granite, and on its geologic and geophysical significance.

Geochemistry of isotopes figures prominently in the geochemistry symposium. In their paper, "The Formation of Rare Gases in Iron Meteorites As a Result of Cosmic Bombardment", P. Signer and A. Nier (U. S.) reported on the distribution in meteorites, as shown in cross-sections, of secondary radioactive isotopes Ne^{21}, He^3, A^{38}, and He^4, formed in the action of cosmic radiation on the meteorite surface.

Similar studies of the He^3/He^4 ratio in meteorites were reported by J. K. Hoffman and A. Nier (U. S.) in their paper, "The Distribution and Analysis of Cosmic Radiation Forming Helium in Four Iron Meteorites"; data on all rare gases were presented by R. Zechringer and W. Hentner (F. G. R.) in their paper, "Primeaval Rare Gases in Certain Stony Meteorites".

R. N. Clayton and H. L. James (U. S.) presented a map of metamorphic zones in the Iron Mountain area, Michigan, drawn from measured isotope ratios O^{16}/O^{18} in various metals, converted to a temperature gradient. It turned out that the biotite metamorphic zone had been formed at 380 to 390° C; the garnet, staurolite, and sillimanite zones at 380 to 390° C; and the iron ore zone at 340 to 650° C.

A similar study of ratios O^{18}/O^{16} had been carried out by S. Epstein and K. Benson (U. S.) for Greenland ice, establishing a periodicity in their changes, which made it possible to map the distribution of contemporaneous ice sheets.

The paper by R. D. Russell and R. M. Farquha (Canada), "Lead Isotopes and Origin of Lead Ores", considered the geochemistry of isotopes in connection with their application in the geology of ore deposits.

These papers show a certain tendency in the field of geochemistry of isotopes, to use precise analytic data in interpreting geologic phenomena.

There were a considerable number of papers on absolute age, some of them being on the Precambrian of the United States (B. Giletti, U. S.); on the Canadian Precambrian shield (R. Russell; Canada); minerals of Finland (O. Kuovo, Finland); and South African monazites (A. Burger, Union of South Africa). Absolute age determinations, in connection with the geologic structure of provinces involved, was considered only in papers by S. Goldich, A. Nier, J. Hofman, and N. Baadsgaard (U. S.), "Stratigraphy and Geochronology of the Precambrian of Minnesota"; by S. Moorbat (Great Britain), "Precambrian Ages in Scotland and Greenland"; and by A. P. Vinogradov and A. I. Tugarinov (U. S. S. R.), "The Problems of East Asia".

L. T. Aldrich's (U. S.) "The Age of Metamorphic Rock" and H. L. Oslop's (U. S.) "The Age of Ancient Granite in the Vicinity of Johannesburg" (on determining the age of South African Precambrian by the Ar/K and Sr/Rb methods, with measurements on eight minerals from a granite massif) described the methods of absolute dating by determining the absolute age of various mineral components of a rock by all known methods.

N. Baadsgaard, J. Lipson, and R. E. Folinsbee (Canada) reported in their paper, "Escape of Radiogenic Argon from Sanidine", on the use of that mineral in dating by the K/Ar method; L. Adams (U. S.) reported on dating sedimentary rocks by their bentonite.

The ionium-protactinium ratio was used by Koshtzy (U. S.) in dating very young formations: Riss, 50,000 years, as determined from oceanic sediments; Wurm, 103,000 years; and Mindel, 141,000 years. Likewise, W. S. Brecker (U. S.) used the ratio Ra^{226} exc. to Ra^{226} equil., obtained from carbonate material, to arrive at the age of contained shells and coral, within 10,000 years; these figures compare with those determined by radiocarbon (C^{14}).

In addition, isotope ratios in absolute dating were discussed in a number of papers: V. Cagliotti, C. Bettinali, A. Giardini, and A. Mele (Italy), "Isotope Ratios in Certain Native Sulfur Deposits and in Sulfur Minerals"; P. M. Gast (U. S.), "Changes in the Isotope Content of Sr^{87}"; L. Legolle (France), "First Observations of Isotope Ratio K^{39}/K^{41} In Rocks"; and F. G. Guterman (Switzerland), "Changes In Isotope Ratios of Meteorite and Terrestrial Osmium".

A. J. Cohen and J. Anania (U. S.) reported on Germanium in Tektites and Other Native Glasses; H. Fechtig, W. Hentner, and Zechringer (F. G. R.) reported on "Diffusive Losses of Argon in Minerals and Stony Meteorites".

Other papers in the field of absolute dating were "on the Age of Cosmic Radiation in Meteorites" (Ye. K. Gerling and L. K. Levskiy, U. S. S. R.); "Age Levels of Precambrian Orogenic Cycles in India" (U. Asvathanarayan, India); "Precambrian Geochronology of the Baltic Shield" (A. A. Polkanov and Ye. K. Gerling, U. S. S. R.); "Absolute Age of Uralian Metamorphics" (L. N. Ovchinnikov, U. S. S. R.); "The Age of Minerals in the Appalachian Province of the U. S." (G. Davis, G. A. Hopson, G. Tilton, and G. Westerhill, U. S.); "The Value of Radiocarbon Data For the Lower Mississippi Alluvial Plain" (J. H. Van Lopick and W. E. Grabau, U. S.); and "Experimental Studies of Discrepancies in the Age of Zircons" (L. T. Silver and S. Deutch, Belgium).

Distributed among the delegates was J. A. Lowdon's summary of age determinations by the Geological Survey of Canada, with data obtained by the K/Ar method for 98 minerals, mostly micas, from various provinces of Canada; and by the U/Th ratio for 14 minerals from Ontario. In six samples the age was determined by the U-Pb, Th-Pb, and K-A methods, with fairly similar results.

There were a number of reports on experiments at high temperatures and pressures, in modeling natural phenomena: Boyd's (U. S.) on the "Equilibrium Phase at A Pressure of 90,000 bars and Temperature of 1600° C" (In connection with the formation of diamonds); O. Tuttle's (U. S.) and P. Wiley (Great Britain), on the genesis of carbonates; and G. Kulerud (U. S.), on Equilibrium Phases in Sulfide Systems (the formation conditions for sulfides at various temperatures and partial pressures of sulfur).

The Twelfth Assembly of the International Volcanologic Association considered a number

of organizational questions, such as the continuance of publication of its magazine, "Bulletin Volcanologique"; a new magazine, "Bulletin of Volcanic Eruptions"; and new symposia: their subject matter, time, and place. It was resolved to hold the 1961 symposium on Ignimbrites, Hyaloclastites, and Associated Formations, at Catagna, with field trips in Italy; and in 1962, on "Predicting the Time and Place of Eruptions and The Relationship Between Magmas and the Nature of Volcanic Eruptions", in Tokyo, with field trips to Japanese volcanoes.

The constitution of the I. V. A. was adopted. Elected to the Executive Committee were A. Rittman (Switzerland), President; V. I. Vlodavets (U. S. S. R.) and G. A. Macdonald (U. S.), Vice-Presidents; and F. Penta (Italy), Secretary.

The incumbent section chairmen were retained: M. Neumann Van Pading (Netherlands), The Active Volcanoes Section; G. S. Borshkov (U. S. S. R.), Volcanophysics; H. Kuno (Japan), Physical Chemistry of Magmas; and B. Géze (France), Paleovolcanism and Plutonism.

The I. V. A. Executive Committee elected P. Evrarde (Belgium), Acting Secretary. An international union of geochemists who are now grouped in three organizations was also considered: The International Union of Applied Chemistry, Geological Congress, and I.V.A. I.G.G.U. After a long discussion it was resolved to set up a Committee on Geochemistry, in the framework of the I. G. G. U. , and to elect its directors. Those elected were L. T. Aldrich (U. S.), Chairman; A. P. Vinogradov (U. S. S. R.) Vice-Chairman; A. I. Tugarinov (U. S. S. R.) and M. Piciotto (Belgium and Italy); B. Géze (France), L. P. Wager (Great Britain), S. Epstein (U. S.), K. Korrens (F. G. R.), and F. G. Guterman (Switzerland), Members.

Elected at the concluding general session of the I. G. G. U. were V. V. Belousov (U. S. S. R.), President; I. Kaplan (U. S.) and J. Bartels (F. G. R.), Vice-Presidents, and G. Laclaveur (France), Secretary General.

THE NINTH SESSION OF THE COMMISSION ON ABSOLUTE DATING OF GEOLOGIC FORMATIONS, AT THE SECTION OF GEOLOGIC AND GEOGRAPHIC SCIENCES, THE U. S. S. R. ACADEMY OF SCIENCES[3]

by

T. B. Pekarskaya

The creation of a Soviet absolute-age scale is the prime task set up by this Section for Soviet geologists and radiologists to accomplish in the coming years. Experts in other branches of geology are participating in this task, so that it will be possible to correlate the absolute and the biostratigraphic scales.

In recent years, much data on the absolute age of various geologic formations, in the Soviet Union as well as in certain adjacent countries, has been recorded. This material has been discussed at the annual sessions of the Commission, and published in its Trudy (Transactions) and Bulletins, as well as in the U. S. S. R. Academy of Sciences periodicals.

In the interim between the Eighth and Ninth Sessions, the Commission carried on extensive work of evaluation and control of the dating of control points, and of their selection, with participation by all operating geochronologic laboratories of the U. S. S. R. , as well as by expert stratigraphers and paleontologists. At the Commission's recommendation, a special collection was gathered during the 1959 field season, of rocks from reliably dated sections and from points used in compiling the scale or its components.

To speed up the gathering of these data, it was necessary to obtain them first from those control points marking the principal boundaries of geologic history: Paleozoic-Mesozoic, Cambrian-Precambrian, Riphean-Proterozoic and Archean-Katarchean.

Several expanded meetings were held in January and February of 1960, presided over by D. I. Shcherbakov (three in Leningrad and two in Moscow), for a detailed discussion of radiochemical, geologic, and stratigraphic data, as a basis for a first variant of the native absolute geochronologic scale.

The current Ninth Session of the Commission was held in Leningrad, July 14-18, 1960. It was a momentous session; it summarized and discussed all material, gathered up to the present time by geochronologic laboratories of the Soviet Union for the first Soviet scale of absolute dating.

Participating in the Ninth Session were geologists, radiologists, chemists, physicists, and geochemists from the several institutions of the U. S. S. R. Academy of Sciences; Academies of the Armenian, Georgian, Kazakh, Ukrainian, and Uzbek S. S. R. ; the Uralian, Bashkirian, Daghestanian, and Yakutian Affiliates of the U. S. S. R. Academy of Sciences; the Siberian Section of the U. S. S. R. Academy of Sciences; Moscow and Leningrad State Universities; All-Union Geological Institute (V. S. E. G. E. I.), and other organizations of the Ministry of Geology, as well as of some provincial geologic institutes.

The following papers were heard and discussed:

[3] IX sessiya Komissii po opredeleniyu absolyutnogo vozrasta geologicheskikh formatsiy pri Otdelenii geologo-geograficheskikh nauk AN SSSR.

1. G. D. Afanas'yev, L. L. Shanin, Yu. V. l'tsman, and V. G. Noskova, "Control Sam-s For the Absolute Geochronologic Scale and rtain Principles to be Followed in Making It". is paper stressed the highly complex nature this task because of the effect of superimposed ocesses and of the diverse origin of natural ects. The data on biotites from extrusive anitic rocks of the western Caucasus are of erest in this respect. It turned out that bio-e from rocks with a maximum potassium con-it and a minimum water content yield the vest age values; the opposite is true for re-rse conditions. The paper discusses geo-ronologic scales of K. Main, H. Lambert, d D. York and cites certain control points for e scale, from Caucasian material: namely, e Lower-Middle Devonian boundary (340 llion years old); Permian-Triassic boundary)0 million years); Upper Pliocene-Apsheronian to 4 million years).

2. N. P. Semenenko, "Precambrian Geo-ronologic Scale, From Data of the Ukrainian ademy of Sciences". Besides the data on solute age of Precambrian formations of the raine, this paper cites the dating of Baykal-yan province rocks, Precambrian deposits in eden, the Kursk series metamorphic schists the Russian platform, and the Anshan schists China. On the basis of these data, the author ers his Precambrian geochronologic scale.

3. M. S. Filippov, L. V. Komlev, and G. N. china, "Age Values Obtained by the Argon ethod for Rocks in the Northwestern Part of e Ukrainian Shield". The data we obtained r three groups of rocks, known to be non-ntemporaneous, correspond to much lower e values (200 to 300 million years younger r the Korosten granite). The authors con-ude that the true age of these three non-ntemporaneous rock groups was camouflaged superimposed metamorphism, some 1500 to 00 million years ago. In their opinion, this ejuvenation" of rocks in metamorphism is of gional nature, throughout the Ukraine; ac-rdingly, they believe the true age of the nitsa granite to be no less than 1860 million ars; i. e., close to that of the Korosten anite.

4. L. V. Komlev and I. M. Gorokhov, "The ge of Some Ukrainian Micas, By the Strontium ethod". These figures were obtained for those cks previously dated by the argon method. ne analyses were carried out on micas from ost ancient rocks of the Ukrainian crystalline ield, namely the Dnepr igneous complex. The incidence of data obtained by the two methods rned out to be satisfactory.

5. M. A. Harris, N. N. Dyadin, F. S. akirova, "A Preliminary Geochronologic Scale or the Precambrian and Paleozoic in the South rals and the Eastern Part of the Russian Platform". From their analyses of 340 samples of igneous, sedimentary, and metamorphic rocks and minerals, the authors determined the age of stratigraphic subdivisions of the Precambrian and Paleozoic and outlined a regional pre-Mesozoic geochronologic scale. All determinations were done with the argon method, on micas, glauconite, feldspar, and occasionally on the whole rock.

6. M. A. Harris, "Information For the U. S. S. R. Geochronologic Scale, In Absolute Figures (Southern Urals and the Eastern Part of the Russian Platform)". It cites original material for the Precambrian II - Archean; Precambrian III - lower Proterozoic; Precambrian IV - middle and upper Proterozoic, Riphean; Paleozoic - Silurian, Devonian, and Carboniferous.

7. L. N. Ovchinnikov, "Uralian Data For the Absolute Geochronologic Scale", giving the results of determining the absolute age of Hercinian granite intrusions, quite common in the Urals; the absolute age of biotite and muscovite from the many granite units of this formation and from the associated pegmatites is determined as 315 ± 8 million years. Of interest is the coincidence of geologic data with those on the absolute age, obtained on biotite and glauconite from paleontologically dated rocks.

8. L. N. Ovchinnikov, M. V. Panova, and V. A. Dunayev, "Correlation of Absolute Age of Paleozoic Extrusives in the Urals With Biostratigraphic Data". The authors discuss the methods of determining the absolute age of extrusives from overall samples. Acid, intermediate, and basic extrusives were analyzed, and their age was determined accurately from the paleontologically dated lateral rocks.

9. G. A. Chernov, "Reconstruction of Geologic Events From Structural Analysis and Absolute Dating By the Argon Method, in the Belokurikhin Massif in the Altay". The author concludes, from a structural analysis and the absolute age figures for the Belokurikhin massif, that the age of all its formations has been overestimated.

10. A. I. Ivanov, G. F. Lyapichev, and N. I. Zamyatin, "On the Absolute Age of Caledonian Intrusions in the Chinghiz Range (Eastern Kazakhstan)". The authors distinguish between three intrusive complexes: Krykkuduk granodiorite, 495 to 500 million years old; Chinghiz granite, 470 million years; and Borovsk granite, 440 million years. These figures are correlated with other data for this segment of the scale. Their complete similarity to L. V. Komlev's figures for Caledonian intrusions of northern Kazakhstan is noted.

11. A. I. Ivanov, V. K. Monich, N. I. Zamyatin, A. N. Nurlybayev, "Absolute Age of